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CHARACTERISTICS OF TWENTY-NINE AEROSOL SAMPLERS TESTED AT U.S. ARMY EDGEWOOD CHEMICAL BIOLOGICAL CENTER (2000 - 2006)

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A summary is given for 29 aerosol samplers evaluated by the Aerosol Sciences Branch at the U.S. Army Edgewood Chemical Biological Center from 2000 - 2006. A one-page summary is shown for each sampler with the description, a picture, specifications, and sampling efficiencies of that sampler. An example comparative subjective ranking methodology is provided for the readers to modify and use.

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PREFACE

The work described in this report was authorized under Project No. 307100.00000. The work was started in January 2000 and completed in April 2006.

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CHARACTERISTICS OF TWENTY-NINE AEROSOL SAMPLERS TESTED AT U.S. ARMY EDGEWOOD CHEMICAL BIOLOGICAL CENTER (2000 - 2006)

1. INTRODUCTION

This report summarizes the results of studies conducted by the Aerosol Sciences Branch (ASB), U.S. Army Edgewood Chemical Biological Center (ECBC), on commercial, university, and government developed aerosol samplers brought to ECBC for testing. Conducted studies evaluated the samplers' sampling efficiencies and characteristics during the test period. This report is not intended to be a comprehensive study or analysis, and if appropriate, provides a record of the measured data to the group that provided the device.

These aerosol samplers were developed for many reasons including, but not limited to, outdoor sampling, indoor sampling, high volume sampling, and replacing fielded military samplers. The samplers use many different mechanisms to collect airborne particles into either dry or wet media. Some were developed to sample air from either very cold or very hot conditions and some were designed to sample from high dust areas. The sampling efficiency measurement methods ECBC used to characterize these samplers are described in detail in published ECBC technical notes and technical reports identified in the Literature Cited section.

This report summarizes the characteristics of 29 aerosol samplers. Included in this report are the samplers' characteristics as given by the manufacturer or as measured by ASB members. The sampler characteristics listed in this report are airflow rate, dimensions, weight, power, and sampling efficiency for inert and biological particles in the size range of 0.5 - 13 µm. None of the samplers were tested with all particle sizes.

A comparative ranking methodology of the samplers is also included for readers to modify and use.

2. AEROSOL SAMPLING

Air samplers are important in the war against terrorism and on the battlefield to detect the presence of chemical, biological, and nuclear aerosols. Specialized aerosol samplers are made for sampling chemical, biological, and nuclear aerosols for various conditions such as short sampling cycles, long sampling cycles, high temperature sampling, and low temperature sampling. Knowledge and use of efficient air samplers enhance the ability to protect soldiers, first responders, and the general public from airborne agents. Samplers and detection systems must be tested and their performance efficiencies determined so that suitable samplers and detectors can be appropriately matched for various challenges.

Each air sampler has multiple components such as an inlet, transmission tubes, a pre-separator skimmer to reject large particles, aerosol concentrating stages, and a collector such as an impactor. An exploded illustration of an aerosol sampler is shown in Figure 1. Each of these components can be either as simple as a filter or as complicated as a multistage virtual impactor aerosol concentrator with a collector. The performance of an aerosol sampler, the sampling efficiency, is the overall end-to-end ratio of the amount of aerosol contained in the sample produced by the sampler to the amount of aerosol contained in the volume of ambient air sampled by the system's inlet. In a well-designed, well-fabricated, well-assembled system, it is the product of the performance efficiencies of the sampler's individual components, variously: aspiration, transmission, collection, retention, and recovery efficiencies.

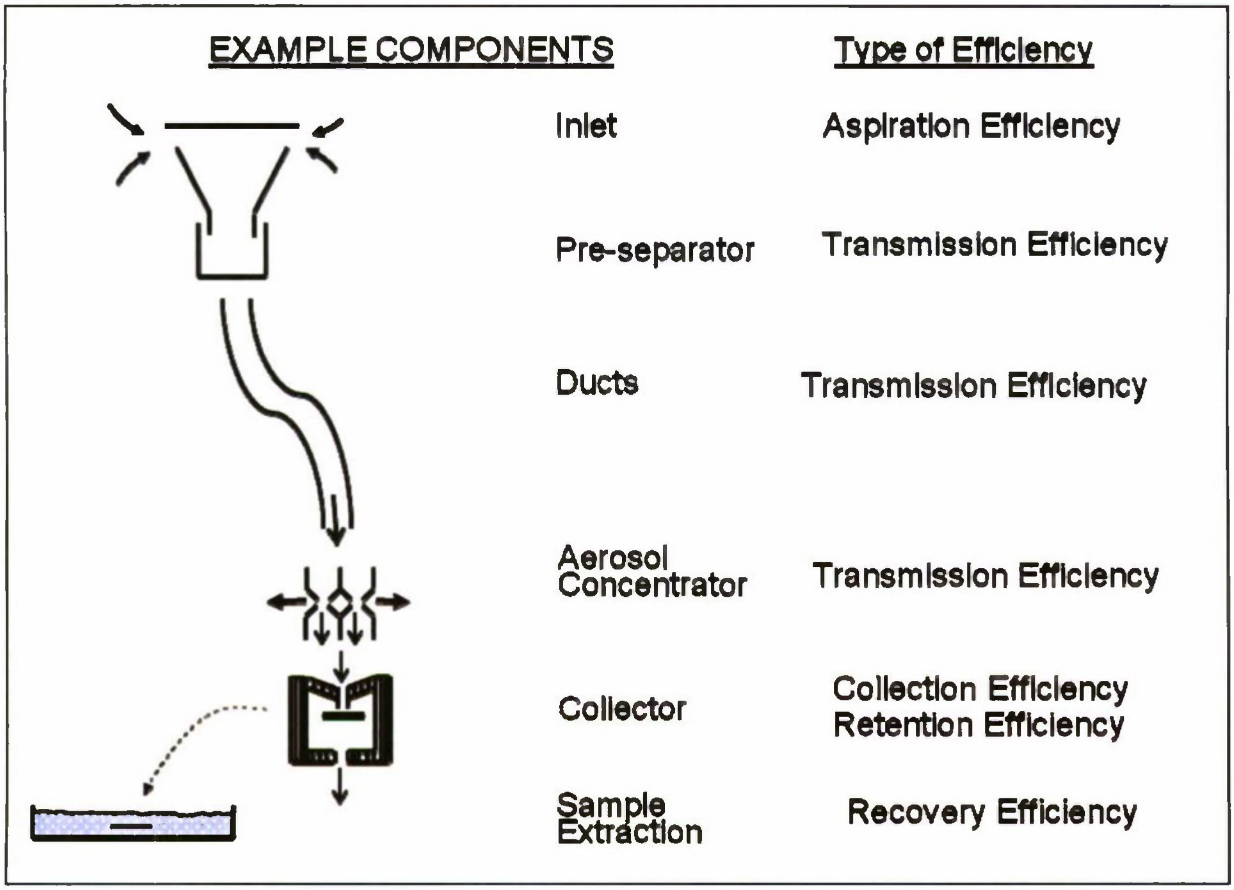

Figure. Illustration of an Aerosol Sampler

The aspiration efficiency of a sampler's inlet describes the efficiency with which particles are extracted from the air and transmitted through the sampler inlet and is dependent on particle aerodynamic size and wind speed. Inlets intended for use either in calm air or indoors can be characterized in an aerosol chamber; however, inlets to be used outdoors, either on moving platforms or in ducts of moving air, must be characterized in an aerosol wind tunnel using the appropriate range of wind speeds. The other components can be characterized in an aerosol chamber.

Transmission efficiency describes the efficiency with which particles are transported from the intake of a component to its collector, and the collection efficiency describes the efficiency with which particles are captured by the collector. Retention efficiency indicates how efficiently particles are retained by the sampler during a long sampling time, e.g., either in an impinger or in a wetted cyclone that stores the collected particles in the active collection fluid throughout the collection time. Particles in the collection fluid can escape into the air (reaerosolization) and be ejected with the exhaust. The collected particles are recovered for analysis, and the efficiency with which they are recovered is indicated by the recovery efficiency. We include this step in the sampling efficiency analysis because it is not until recovery has been accomplished that we have a sample, and there are instances of systems with inefficient recovery steps making this step an important determinant of end-to-end sampling efficiency. All efficiencies described above can depend on particle size, density, charge, composition, and biofactors.

There has been ambiguity in the use of these efficiency terms in the literature. In particular, the term collection efficiency is used to mean any of the following experimental observations: (1) how much aerosol comes out in the sample; (2) how much of the aerosol that enters a sampler inlet does not come out in the exhaust. In that case, either the "collected" aerosol may be in the sample or it may be stuck on the walls inside the sampler. In reading the literature and in discussions, it therefore becomes critical to clarify the context of a term's use to understand its meaning; in our experience, this can lead to misunderstandings. We suggest that sampling efficiency be reserved to refer to the overall, end-to-end efficiency from the amount of aerosol available in the air outside the inlet to the amount of aerosol contained in the final sample to be either analyzed or preserved. In addition, the other efficiency terms should always be used in connection with a component or subset of components. Confusion arises when an aerosol sampler is called an aerosol collector, and its performance is then referred to as its collection efficiency. The term collection efficiency cannot even be assumed to apply only to the performance of the collector element of a sampler. For example, a simple duct has a transmission efficiency, and that is its purpose; however, a duct also has a collection efficiency that measures what fraction of aerosol entering the duct is captured and retained. This applies to losses at all components of a sampler, and it is an important measurement when doing a diagnostic analysis of the contribution of components to the overall performance of a sampler. The goal is to develop an understanding of the sampler, and this is best accomplished if a mass balance is achieved for each component by measuring the amount of aerosol collected, transmitted, and in the case of split flows like virtual impactors, the amount rejected. When done properly, the result is a sampling efficiency that matches the products of all the relevant component efficiencies in the sampling train unless there are problems in the connections between components such as changes in duct diameter, offsets in mating the components, or leaks. Real world instances of all three of these have been seen at ECBC, resulting in losses of as much as 95% of the aerosol, depending on particle aerodynamic diameter to the overall performance of a sampler.

Bioorganisms have two additional issues: survival fraction and culturable fraction. Survival of an organism can be measured by flow cytometry using different dyes that reveal viable versus non-viable organisms, and by other life function measures such as ATP. The culturability is determined by plating. These are reported as fractions rather than efficiencies because they are characteristics of the aerosol in the sample not the amount of aerosol in the sample. For samplers that affect the viability of organisms in the aerosol, it is important to make this measurement, as it would be used in the field in terms of sampling and analysis.

2.1 Aerosol Components

All aerosol samplers have inlets through which the aerosol enters the sampler. Many inlets are simple with just a tube sampling the air; however, other inlets are complicated and may have a rain hat, bug screen, and/or pre separator. A rain hat prevents rain from entering the inlet, and a pre separator removes unwanted large particles. The transmission region can be simple with a tube connecting the inlet to the collection site, or it can be complicated with aerosol concentrators, bends, constrictions, and expansions.

Aerosol concentration is increased by passing the aerosol through virtual impactors. Virtual impactors have accelerating and matching receiving nozzles. Only 5 - 10% of airflow (called the minor airflow) through an accelerating nozzle is pulled through the receiving nozzle. The major airflow is pulled perpendicular to the initial airflow direction. Particles with high inertia continue to travel in the original direction and enter the minor airflow. Each virtual impactor has a particle cut size above which the particles enter the minor airflow. The aerosol concentration is achieved by particles larger than the cut size entering the minor airflow with 5-10% of the original airflow. The concentrated aerosol enters the aerosol collection region and gets collected as described in Section 2.2.

2.2 Aerosol Collection Mechanisms

Aerosol samplers collect particles from air using different mechanisms (Cox and Wathes, 1995). Mechanisms include impaction, interception, sedimentation, diffusion, and electrostatic attraction. A brief summary of the collection mechanisms used in the present study is provided below.

Particle deposition by impaction is achieved when the aerosol flow makes sharp turns, resulting in high inertial particles continuing in their initial path and impacting onto surfaces. The impaction deposition method is used to collect large particles with high inertia. Particle deposition by impaction can be achieved on either stationary plates or rotating wetted surfaces. Impaction is the mechanism used in air samplers to remove unneeded large particles from the air.

Particle deposition by interception is achieved when large particles pass within one particle radius of an object. The flow is assumed laminar, and the particle follows a flow streamline adjacent to the object where the particle is captured.

Particle deposition by sedimentation is achieved when large particles are in a small diameter tube for a long time. Particles settle to the bottom due to gravitational forces and deposition increases with particle size for particles $\geq$1.0 μm. This mechanism is not used in active aerosol collection because of the long settling time.

Particle deposition by diffusion is achieved when particles travel from a high to a low concentration area and deposit on a surface. The deposition is due to Brownian motion and is therefore limited to particles sizes $\leq$0.25 μm. Particle sizes used in the present study were $\geq$0.5 μm; therefore, collection by diffusion was not a dominant mechanism.

Particle deposition by electrostatic attraction is achieved when charged particles deposit on surfaces due to electrostatic forces. Electrostatic forces can also be a source of surface deposition on the inlet and the transport tube prior to the collection area (Cox and Wathes, 1995) contributing to decreased sampling efficiency.

3. SAMPLERS TESTED

Twenty-nine sampler results are provided in this report and the samplers are grouped according to the method used for collecting the particles:

a. <u>Aerosol concentrators with filter collection</u>: One Stage MicroVIC® Aerosol Concentrator, Two Stage MicroVIC® Aerosol Concentrator, XMX/2A, Modified XMX (SCP 1005), and EULSI (Eight Unit Linear Slot Impactor). These sampler characteristics are given in Appendixes 1-5 and Table 1.

b. <u>Filter collection without aerosol concentration</u>: Rotating Arm Sampler (RAS) and Sandia Met-One Sampler. These sampler characteristics are given in Appendixes 6-7 and Table 2.

c. <u>Samplers that use impingement and/or impaction onto a wetted surface</u>: SKC BioSampler®, AGI 30 Impinger, Midget Impinger, Two Stage MicroVIC® connected to an SKC BioSampler®, and Aerosol to Hydrosol Transfer System (AHTS). These sampler characteristics are given in Appendixes 8-12 and Table 3.

d. <u>Samplers that impact particles on a rotating wet surface:</u> BioCapture™ BT-500, BioCapture™ BT-550, BioCapture™ BT-650, and BioBadge® Aerosol Sampler. These sampler characteristics are given in Appendixes 13-16 and Table 4.

e. <u>Samplers that collect particles in a wetted wall cyclone</u>: PHTLAAS™ Air Sampler #3, PHTLAAS™ APAS #4, Smart Air Sampler System (SASS 2000Plus®), Spin Con, Omni 3000, BioGuardian® 1.02, BioGuardian® 4.02, BioGuardian® 12.02, and BioGuardian® 12.03. These sampler characteristics are given in Appendixes 17-25 and Table 5.

f. <u>Samplers that collect particles using electrostatic attraction:</u> ALPES #1 and ALPES #2. These sampler characteristics are given in Appendixes 26-27 and Table 6.

g. <u>Samplers that collect particles on agar plates:</u> MAS-100®, and Andersen One Stage Impactors. These sampler characteristics are given in Appendixes 28-29 and Table 7.

4. RESULTS

4.1 <u>Sampler Summaries</u>

Tables 1-7 show the sampler type, manufacturer, and address, the ECBC report number (if available), the type of aerosol concentrator, airflow rates, liquid output volume, power, weight, size, and sampling efficiency as measured by the ASB. The samplers are put into different tables based on the collection mechanism shown in Section 3. The efficiency covers the particle range between 0.5 and 13 μm, although data was not always obtained across the complete particle range.

Table 1. Summary of Aerosol Concentrators

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Aerosol Sampling Efficiency [Size (μm), Sampling Efficiency (%)]
One Stage MicroVIC® (Appendix 1)	MesoSystems Technology, Inc 1021 N. Kellogg St. Kennewick, WA 99336	TR-249 Aug-02	One Stage Aerosol Concentrator 30 to 3 L/min	30 Designed 30 Measured	Concentrated air output	NA (lab pumps used)	0.7	2x2x3	(1, 47), (3.5, 56) (5, 54), (8, 60) (10.5, 58)
Two Stage MicroVIC® (MV-F) (Appendix 2)	MesoSystems Technology, Inc. 1021 N. Kellogg St. Kennewick, WA 99336	TN-014 Mar 03	Two Stage Aerosol Concentrator 450 to 12.5 L/min	450 Designed 423 Measured	Concentrated air output	323	24.7	19X9X29.5	(0.5, 18) (1, 52),(2, 63) (3.8, 28) (5, 26),(9,7)
XMX/2A (Appendix 3)	Dycor Technologies Ltd, 1851-94 Street NW Edmonton Alberta, Canada	TR-364 Feb 04	Three Stage Aerosol Concentrator 800 to 1 or ≤1 L/min	800 Designed 742 Measured	Concentrated air output	780	25.8	8.5x18x18	(3, 42) (5, 30) (5.5, 25)
Modified XMX(SCP 1005) (Appendix 4)	Dycor Technologies Ltd 1851-94 Street NW Edmonton Alberta, Canada	TR-364 Feb 04	Three Stage Aerosol Concentrator 900 to (1 or ≤1 L/min)	900 Designed 870 Measured	Concentrated air output	1,114	23.3	18x7x13	(2, 28), (5, 30) (9, 14)
EULSI (Appendix 5)	Texas A & M University, College Station, TX	TN-025 Oct 06	One Stage Aerosol Concentrator 270 to 1 L/min	270 Designed 367 and 370 Measured	Concentrated air output	116	very heavy, mounted on wheels	26x22x36	(1, 21), (3, 35) (5, 37), (7, 36), (9, 32) (12, 28)

Table 2. Summary of Samplers that use Filters to Collect Particles

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Aerosol Sampling Efficiency (Size (μm), Sampling Efficiency (%))
Rotating Arm Sampler (Appendix 6)	AST, ECBC, APGEA, MD 21010	TR-249 Aug-02	Filter Collection	Probe 1, 31 Probe 2, 23	Filter Collection	Not Optimized	Too Heavy to Lift	34x22x60	(2, 95) (4.4, 91), (7,90) (9, 92), (13, 78)
Sandia Met-One Sampler (Appendix 7)	Sandia National Labs Albuquerque, NM	NA	Filter Collection	112 Measured	Filter collection	292	88 w/stand	Main unit, 24x20x9 w/stand and inlet: 24x33x31	(1, 13), (3,12) (5, 67), (7.5, 90) (9.5, 87)

Table 3. Summary of Samplers that use Impingement or Impaction in Liquid to Collect Particles

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Aerosol Sampling Efficiency (Size (μm), Sampling Efficiency (%))
AGI 30 Impinger (Appendix 8)	Ace Glass Inc. Vineland, NJ	NA	Impaction into liquid	12.5 Designed 12.5 Measured	<20 mL Depends on Sample Time	Uses External Pump	4.7 oz Without pump	Height: 10.8 Diam: 1.5	(1, 27) (2, 27), (4, 67) (5.1, 59)
Midget Impinger (Appendix 9)	SKC, Inc., Eighty-Four, PA	NA	Impaction into liquid	1 Design 1 Measured	<20 mL Depends on Sample Time	Uses External Pump	2.7 oz Without Pump	Height: 7.3 Diam: 1	(1, 13), (2, 94), (4, 85), (5.1, 38)
SKC Bio-sampler® (Appendix 10)	SKC, Inc., Eighty-Four, PA	NA	Impaction into liquid	12.5 Designed 12.5 Measured	<20 mL Depends on Sample Time	Uses External Pump	5.9 oz	Height: 8.5 Diam: 1.5	(1, 96) (3, 98) (5, 79) (7, 62)
Two-Stage MicroVIC® to SKC Bio-Sampler® (Appendix 11)	MesoSystems Technology, Inc 1021 N. Kellogg St. Kennewick, WA 99336	TN-014 Mar 03	2 Stage Aerosol Concentrator Connected to the SKC BioSampler	400 Designed	<20 mL Depend on sample time	323 plus pump for SKC	25	19x9x30	(0.5, 9), (1, 15) (2, 27), (3.8, 9) (5, 10), (9, 2)
AHTS (Appendix 12)	Texas A & M University Texas		Impaction on to a Wetted Surface	1	0.3 mL/min	27	25	23x9x18	(2, 67), (3, 78) (5, 71), (7, 38)

Table 4. Summary of Samplers that use Impaction on a Rotating Wetted Surface to Collect Particles

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Aerosol Sampling Efficiency (Size (µm), Sampling Efficiency (%))
BioCapture™ BT 500 (Appendix 13)	MesoSystems Technology, Inc. 1021 N. Kellogg St. Kennewick, WA 99336	TR-249 Aug-02	Collection on to a Wetted Rotating Surface	150 measured	3-7 mL in 7 min	Battery 12 V, 3 Ah	9 lb	12x6x8	(1, 11) (3.5, 22) (5, 19) (5.5, 6) (7, 7) (9, 5)
BioCapture™ BT 550 (Appendix 14)	MesoSystems Technology, Inc. 1021 N. Kellogg St. Kennewick, WA 99336	TN-014 Mar 03	Collection on to a Wetted Rotating Surface	150 Designed 150 measured	1.9 - 7.3 mL	Battery 12 V, 3 Ah	10 lb	12x6x8	(0.5, 12) (1, 31) (2, 38) (3.8, 29) (5, 32) (9, 28)
BioCapture™ BT 650 (Appendix 15)	MesoSystems Albuquerque, NM	TN-029 Apr 07	Collection on to a Dry rotating surface	200 Designed 192 - 194 Measured	0 - 9.5 mL	Lithium Battery	7.5 lb Without Battery	5x6x14	(0.5, 8), (1,17) (3.0, 60), (5.9, 48) (8, 44) (9.6, 51)
BioBadge® (Appendix 16)	MesoSystems Technology, Inc 1021 N. Kellogg St. Kennewick, WA 99336	TN-024 May 05	Collection on to a Dry rotating impeller	35 Designed; 32 - 37 Measured on	onto dry disc and washed with 5 mL	Battery	0.55 lb	6x3x2	(1, 9), (2.3, 38) (3,64), (8, 74)

Table 5. Summary of Samplers that use Wetted Wall Cyclone to Collect Particles

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Maximum Aerosol Sampling Efficiency (Size (μm), Sampling Efficiency (%))
PHTLAAS™ 3 (Appendix 17)	Zaromb Research Corp 9S706 William Drive Hinsdale, IL 60521	TR-267 Nov 02	Collection in a Wetted Wall Cyclone	Adjustable Tested at 317	35 mL After 10 min of sampling	85	20	18x14x8	(1, 66), (4, 84) (6, 68), (8, 64) (10, 63)
PHTLAAS™ 4 (PHTLAAS™ APAS-2) (Appendix 18)	Zaromb Research Corp 9S706 William Drive Hinsdale, IL 60521	TN-30 Apr 07	Collection in a Wetted Wall Cyclone	306 Measured	18 mL after 10 min of Sampling	49	5.5 without battery	Height: 20 Diam: 6	1,55), (3, 88) (5, 85) (8, 78)
SASS 2000 Plus® (Appendix 19)	Research International 18706 - 142nd Ave N.E. Woodinville, Washington,	TN-021 Dec 04	Collection in a Wetted Wall Cyclone	265 Designed 307 Measured	5 mL	14.4	9 lb With battery	Height: 13 Diam: 8	(1, 5), (3, 36) (5, 52), (7, 65) (9, 54), (10, 60)
SpinCon (Appendix 20)	Midwest Research Inst 425 Volker Blvd Kansas City, MO 64110	TN-027 Oct 06	Collection in a Wetted Wall Cyclone	400 or 450 Designed 457 Measured	5.9 - 11.5 mL	283	46	15x10x19	(1, 47) (3, 56) (3.5, 15) (5, 14)
Omni 3000 (Appendix 21)	Sceptor Industries, Inc. Kansas City, MO	TN-028 Oct 06	Collection in a Wetted Wall Cyclone	300 Designed 268-286 Measured	10.7 mL to 12.0 mL	74 W to 92 W	14 without battery 21 with battery	8.5x7x17	(0.5 38) (1, 44) (3, 92) (5, 92) (8, 34)
BioGuardian® 1.02 (Appendix 22)	InnovaTek 350 Hills St., Suite 104 Richland, WA 99352 509-375-1093	TN-013 Mar 03	Collection in a Wetted Wall Cyclone	90 Designed 88 Measured	10 mL Designed 7.7mL Measured	58	17	12x11x17	(1, 21), (2, 52) (4, 39), (6, 40)

Table 5. Continued

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Maximum Aerosol Sampling Efficiency (Size (µm), Sampling Efficiency (%))
BioGuardian® 4.02 (Appendix 23)	InnovaTek 350 Hills St., Suite 104 Richland, WA 99352 509-375-1093	TN-013 Mar 03	Collection in a Wetted Wall Cyclone	350 Designed 351 Measured	10 Designed 11.6 Measured	137 Measured	32.5	12x10x18	(1, 34), (2, 49) (4, 47), (6, 43)
BioGuardian® 12.02 (Appendix 24)	InnovaTek 350 Hills St., Suite 104 Richland, WA 99352 509-375-1093	TN-013 Mar 03	Collection in a Wetted Wall Cyclone	1,100 Designed 1,000 Measured	12.6 Measured	421 Measured	>75	Height: 25 Diam: 14.5	(1, 27), (2, 32) (4, 32), (6, 26)
BioGuardian® 12.03 (Appendix 25)	InnovaTek 350 Hills St., Suite 104 Richland, WA 99352 509-375-1093	TN-023 May 05	Collection in a Wetted Wall Cyclone	1,000 Designed 824-896 Measured	27	378 Measured	70	Height: 25 Diam: 15	Test Unit #1: (1, 52) (2, 66) (4.5, 54) (8.5, 54)

Table 6. Summary of Samplers that use Electrostatic Attraction to Collect Particles

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Maximum Aerosol Sampling Efficiency (Size (µm), Sampling Efficiency (%))
ALPES #1 (Appendix 26)	Savannah River Technology Center, Aiken, SC	TN-017 Jan 04	Electrostatic Collection	250 Designed 235 Measured	12.1 - 21.3	24.4	Not Measured	22x6x10	(0.5, 44) (1, 40) (5, 57)
ALPES #2 (Appendix 27)	Savannah River Technology Center, Aiken, SC	NA	Electrostatic Collection	287 Measured	11.8 - 24.1	33.4	14	12x7x21	(3, 57) (5, 51) (8, 55)

Table 7. Summary of Samplers that Collect Particles on Agar Plates

Type	Manufacturer Information	ECBC Report No. and Date	Aerosol Concentrator Type	Airflow Rate Information L/min	Liquid Output Volume, if applicable, mL	Power Usage of the Unit, Watts	Weight, lb	Size, in.	Maximum Aerosol Sampling Efficiency (Size (µm), Sampling Efficiency (%))
MAS-100® (Appendix 28)	EM Science, Gibbstown, NJ	TN-019 Oct 04	Impaction onto Agar Plates	100 Designed 100 Measured	No Liquid Output	36 Or battery operated	4.9 with battery	Height: 10.3 Diam: 4.3	(1, 7), (2, 15) (3, 59), (4, 68) (5, 66), (7, 62)
One stage impactor (Andersen Single-stage viable microbial sampler) (Appendix 29)	ThermoAnderson Smyrna, GA	TN-019 Oct 04	Impaction onto Agar Plates	28.3 Designed 28.3 Measured	No Liquid Output	Uses a separate pump	1.3 lb	Height: 2.9 Diam: 4.13	(1, 58) (2, 56) (4, 89) (8, 44)

4.2 Evaluation of Samplers

All samplers can be evaluated using the following six attributes listed in Table 8: sampling efficiency (percent), portability (pound), power source (AC or DC), power (Watt), consumables, and maturity. Each sampler can be ranked from 1 to 5, with 5 being the most desirable. Obviously, the rankings are subjective. Therefore, the reader is advised to select attributes that are important for each case and examine the individual sampler summary sheets given in the Appendixes.

Samplers with higher sampling efficiencies are given a higher score. Portable samplers are also given a higher score; but, these samplers may not have high airflow rates. Battery operated samplers are given a higher score; however, due to battery power, the airflow rate and sample time will be limited in these samplers. The power availability in a sampling location will dictate which samplers can be used. Samplers that use low power are given higher scores. Samplers that use very little consumables are also given a higher score due to low expenses of the materials and less human interaction. Mature fielded samplers are given a higher score due to their immediate use in the field.

Table 8. Numerical Basis for Ranking Samplers. Sampler attributes are ranked from 1 to 5 with 5 being the most desirable.

Attribute						
	Particle Size Range (μm)	Efficiency (%) 80 - 100	60 - 80	40 - 60	20 - 40	<20
Efficiency (%)	0.5 - ≤1	5	4	3	2	1
	>1 - ≤5	5	4	3	2	1
	>5 - 10	5	4	3	2	1
Portability		Weight (lb) <5	5 - 15	15 - 30	30 - 50	>50
		5	4	3	2	1
Power Source		Electrical - field use DC				AC
		5				1
Power		Power (Watt) <10	10 - 50	50 - 100	100 - 500	>500
		5	4	3	2	1
Consumables		Particle Collection Type	Filter	Dry Surface	Wet Surface	Agar Plates
			5, 4	3	2	1
Maturity		Fielded			Laboratory developmental	
		5	4	3	2	1

5. CONCLUSIONS

Aerosol sampler characteristics and sampling efficiency results of 29 samplers are provided in this report. Sampler characteristics are listed in tables for easy sampler comparisons.

The selection of a sampler for a particular application involves many considerations: laboratory or field use, sampling location, amount of air volume sampled, collection media, liquid sample volume, sampling mechanism, and particle size range of optimum collection.

Ambient conditions also need to be considered during the selection process. Samplers have been developed using many different mechanisms to collect air borne particles in either dry or wet media. Some samplers were developed to sample air from very cold or very hot conditions, and some were designed to sample from high dust areas. In addition, the sensitivity of the sampler to a particle size range of interest and the sampler's collection efficiency for that particle size should match, and the sampling efficiency should be high. Determining the sampler's sampling efficiency was the primary objective of the present study. Portability and battery operation may also be important for personal application, especially for remote field application and the lack of availability of a power source.

It should also be noted that all samplers were tested under laboratory conditions at room air temperature without wind. When operated under outdoor conditions, the sampling efficiency may be different from what was recorded under laboratory conditions due to the wind effects.

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ACRONYMS

AHTS	Aerosol to Hydrosol Transfer System
APS	Aerodynamic Particle Sizer
ASB	Aerosol Sciences Branch
Bg	*Bacillus globigii*
ECBC	Edgewood Chemical Biological Center
EULSI	Eight Unit Linear Slot Impactor
CF	Concentration Factor
MAS	Microbial Air Sampler
L/min	Liter per minute
NA	Not Applicable
ND	No Data
PHTLAAS	Portable High Throughput Liquid Absorption Air Sampler
RAS	Rotating Arm Sampler
rpm	revolutions per minute
PSL	PolyStyrene Latex spheres
OA	Oleic Acid oil droplets
SASS	Smart Air Sampler System™
std dev	standard deviation

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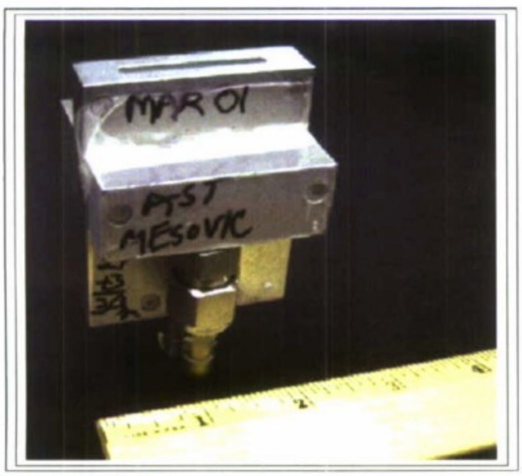
APPENDIX 1

One Stage MicroVIC® Aerosol Concentrator (ECBC-TR-249)

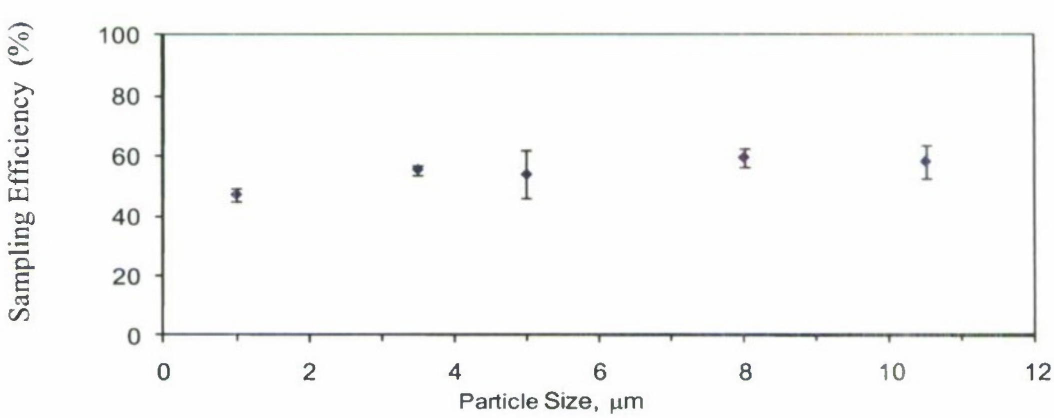
MesoSystems Technology, Inc., Kennewick, WA

This is a one stage aerosol concentrator in which air enters the sampler through a slit on top at an airflow rate of 30 L/min. There are two narrow slits on either side of the sampler to pull the major airflow of 27 L/min out of the sampler. The minor airflow of 3 L/min passes out the bottom. Concentrated aerosol in the minor airflow was collected on filters during the sampling efficiency tests. This test was started in January 2000.



Designed airflow rate (L/min)	30
Measured air sampling rate (L/min)	30
Minor airflow (L/min)	3
Overall dimensions (in.) Length Width Height	 2 2 2.5
Weight (lb)	0.7 lb
Power consumption (W)	N/A (Lab pumps used)
Particle size (μm)	Sampling efficiency (% ±1 std dev)
1	47.4 ± 1.9
3.5	55.7 ± 1.6
5	54.0 ± 8.0
8	59.7 ± 2.9
10.5	58.3 ± 5.6

See ECBC-TR-249 for more explanation.

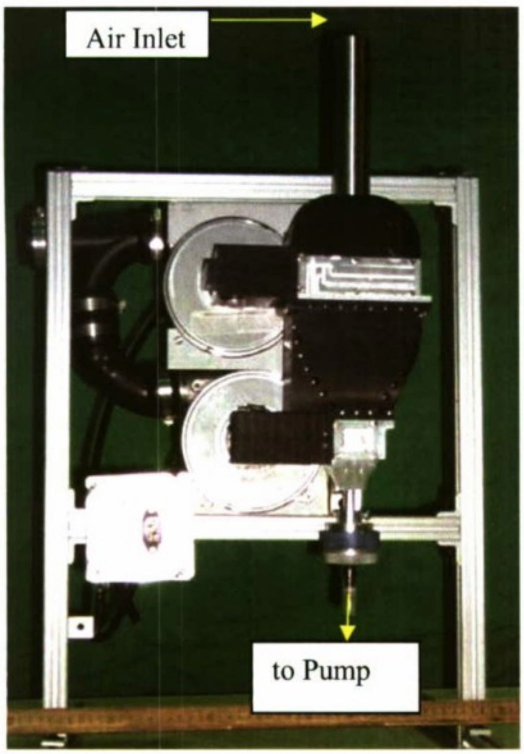


APPENDIX 2

Two Stage MicroVIC® Aerosol Concentrator Connected to a Filter (ECBC-TN-014)

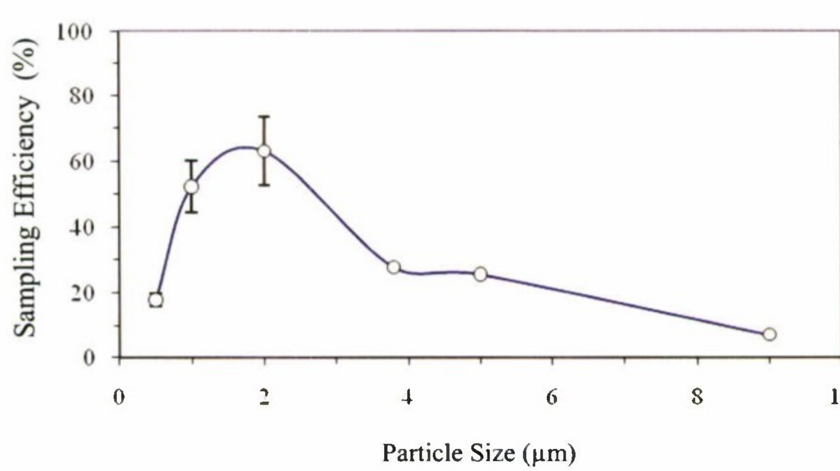
MesoSystems Technology, Inc., Kennewick, WA

This is a two stage aerosol concentrator designed to concentrate particles from a 450 L/min airflow to a 12.5 L/min airflow. Air enters the sampler through an opening on top and exits through the bottom. Laboratory pumps pulled the minor airflow through a filter at a flow rate of 12.5 L/min to capture particles from the concentrated airstream. This test was started in May 2002.



Designed airflow rate (L/min)	450
Measured air sampling rate (L/min)	423
Minor airflow rate (L/min)	12.5
Overall dimensions (in.) Length Width Height	 19 9 29.5
Power consumption (W)	323
Weight (lb)	24.7
Particle size (μm)	Concentration efficiency (%)
0.5	17.9 ± 2.1
1	52.3 ± 7.8
2	63.0 ± 10.4
3.8	27.8 ± 0.7
5	25.6 ± 0.3
9	7.0 ± 0.4

See ECBC-TN-014 for more explanation.



APPENDIX 3

Aerosol Concentrator XMX/2A (ECBC-TR-364)

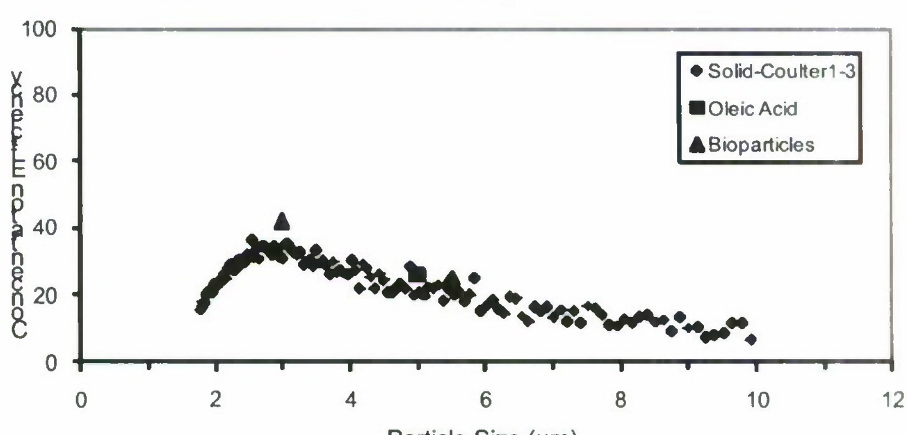
Dycor Technologies Ltd., Alberta, Canada

The XMX/2A is a three stage aerosol concentrator designed to pull 800 L/min of air. A rain cap on top of the inlet prevents rain water from entering the sampler, and a wire mesh around the inlet prevents large particles and bugs from entering the inlet. An external pump pulled the concentrated airflow through a 47 mm filter in tests where a sample needed to be collected for analysis. An APS was connected to the output of the concentrator in tests where the APS was used as the analyzer. This test was started in January 2000.

Designed airflow rate (L/min)	800
Measured air sampling rate (L/min)	742
Minor airflow (L/min) Monodisperse tests Polydisperse tests	 0.3, 0.5, and 1.0 0.5 and 0.9
Dimensions (in.) Length Width Height	 8.5 18 18
Weight (lb, oz)	24, 12
Power (W) Voltage (V) Current (A)	780 115.6 6.99

Particle Type	Particle Size (μm)	Concentration Efficiency (%)	Minor airflow rate (L/min)
Fluorescent oleic acid	5 5	25.9 23.9	0.5 0.3
Bioaerosol	3 5.5	42.3 25.0 ± 4.1	1 (All bioaerosols)
Solid particles (Aluminum oxide; Coulter analysis)	5	30.0	1

See ECBC-TR-364 for more explanation.



APPENDIX 4

Modified XMX (SCP 1005) Aerosol Concentrator (ECBC-TR-364)

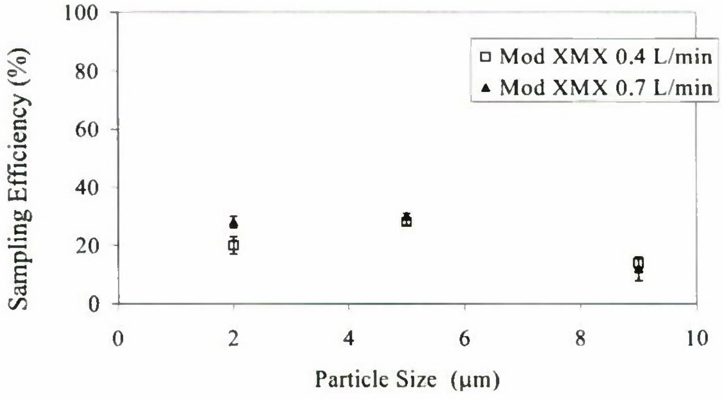
Dycor Technologies Ltd., Alberta, Canada

The Point Detection Team at ECBC modified the XMX (SCP 1005) by installing a larger blower to pull 900 L/min of air instead of the designed 500 L/min. The modified XMX is a three stage aerosol concentrator. This sampler has a rain cap on top of the inlet to prevent rain water from entering the sampler and a wire mesh around the inlet to prevent large objects or bugs from entering it. In tests where a sample needed to be collected for analysis, an external pump pulled the final concentrated airflow through a 47 mm filter. In experiments where the analysis was by an APS, the APS was connected to sample the final concentrated, minor airflow. This test was started in January 2000.

Designed airflow rate (L/min)	900
Measured airflow rate (L/min)	870
Minor airflow through filter (L/min)	0.43 and 0.68
Dimensions (in.) Length Width Height	 18 7 13
Weight (lb, oz)	23, 4
Power (W) Voltage (V) Current (A)	1114 121 9.4

Particle Type	Particle Size (μm)	Concentration Efficiency (%)	Minor airflow rate (L/min)
PSL	2	20 ± 3	0.43
	2	28 ± 2	0.68
Fluorescent oleic acid	5	28 ± 1	0.43
	5	30 ± 1	0.68
	9	14 ± 2	0.43
	9	12 ± 4	0.68

See ECBC-TR-364 for more explanation.



APPENDIX 5

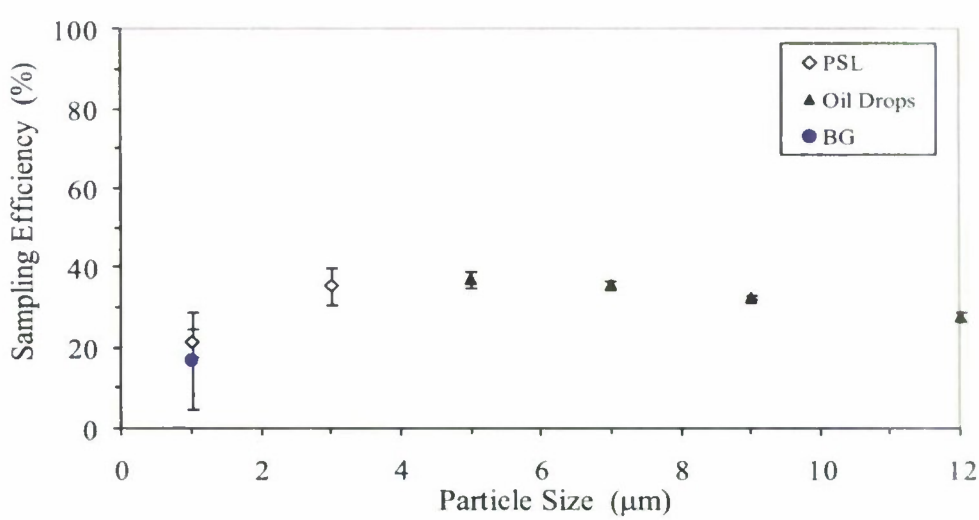
EULSI (Eight Unit Linear Slot Impactor) (ECBC-TN-025)
Texas A&M University,
College Station, TX

EULSI is a one stage aerosol concentrator. It has eight linear slots to accelerate the air and eight matching receiving slots to capture the particles. This test was started in March 2004.

Designed airflow rate (L/min)	270
Measured major airflow rate (L/min) (measured at ECBC)	370.2 – Oleic acid tests 367.1 – PSL tests
Measured minor airflow rate (L/min) (measured at ECBC)	27.2 – Oleic acid tests 24.1 – PSL tests
Power (W) (measured at ECBC)	115.5
Weight	Very heavy – Mounted on wheels
Dimensions (in.) Length Width Height	 26 22 36

Particle Size (μm)	Particle Type	Sampling Efficiency (%)
1	PSL	21.1 ± 3.3
3	PSL	35.3 ± 4.8
5	Oil Drops	36.9 ± 2
7	Oil Drops	35.5 ± 1.3
9	Oil Drops	32.3 ± 0.5
12	Oil Drops	27.7 ± 1.2
1	BG	16.7 ± 12.1

See ECBC-TN-025 for more explanation.

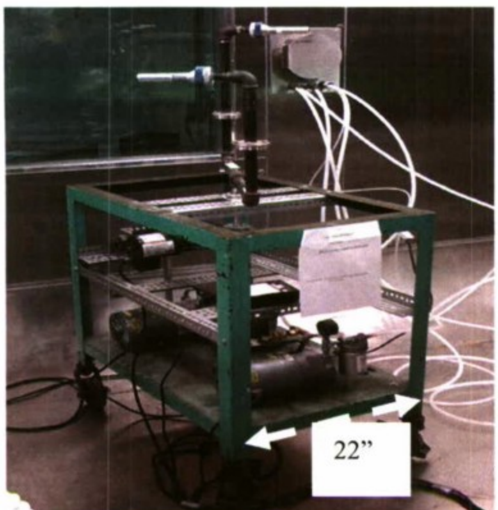


APPENDIX 6

Rotating Arm Sampler (RAS) (ECBC-TR-249)

U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD

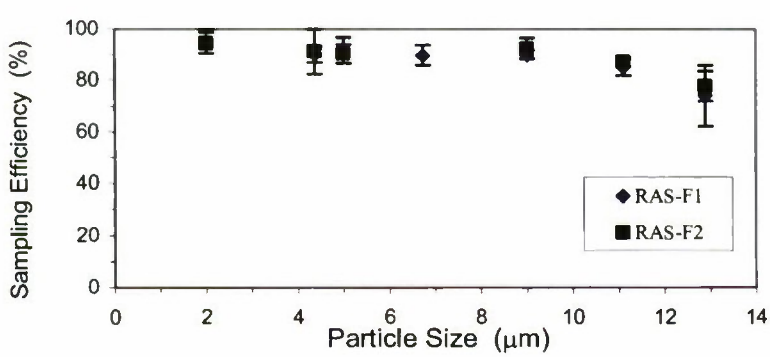
The RAS is mounted on a movable cart for convenient transport. It has two arms with a filter holder attached to each arm. Arm #1 is 14 in. long and 16 in. high, and Arm #2 is 11.5 in. long and 20 in. high. Both arms rotate horizontally around a central axis. There are three pulleys used to rotate the sampler with rotational speeds of 30, 38, and 47.6 rpm. The sampling efficiency tests were conducted at 30 rpm. There is a 4 in. long, 0.94 in. diameter probe, which serves as an air inlet, in front of each filter holder. Airflow rates through the filters were 31.3 L/min for Arm #1 (long arm), and 22.5 L/min for Arm #2 (short arm). The rotational speed and airflow rates through the filters were chosen so there would be a similar volume of air covered by the probe opening and the pump. This test was started in January 2000.



Measured air sampling rate (L/min) Arm #1 (long) Arm #2 (short)	 31.3 22.5
Dimensions (in.) Length Width Height	 34 22 60
Weight (lb)	too heavy to lift
Power consumption (W)	not optimized

Particle Size (µm)	Sampling Efficiency (%) Arm #1 (long) 31.3 L/min airflow rate	Arm #2 (short) 22.5 L/min airflow rate
2	95.2 ± 4.7	94.5 ± 4.1
4.4	90.0 ± 3.2	91.2 ± 8.8
5	91.5 ± 5.1	90.3 ± 3.7
6.7	89.6 ± 4.0	---
9	89.9 ± 1.9	92.3 ± 3.9
11.1	85.1 ± 3.1	87.2 ± 1.8
12.9	73.9 ± 11.8	77.8 ± 5.8

See ECBC-TR-249 for more explanation.

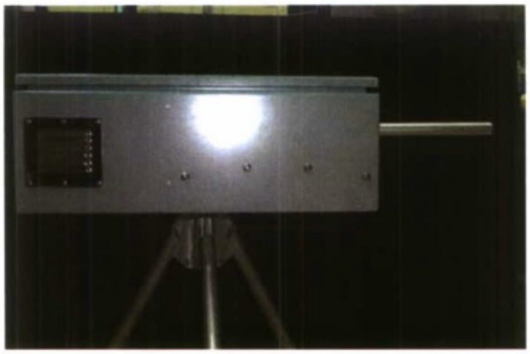


APPENDIX 7

Sandia Met-One Sampler

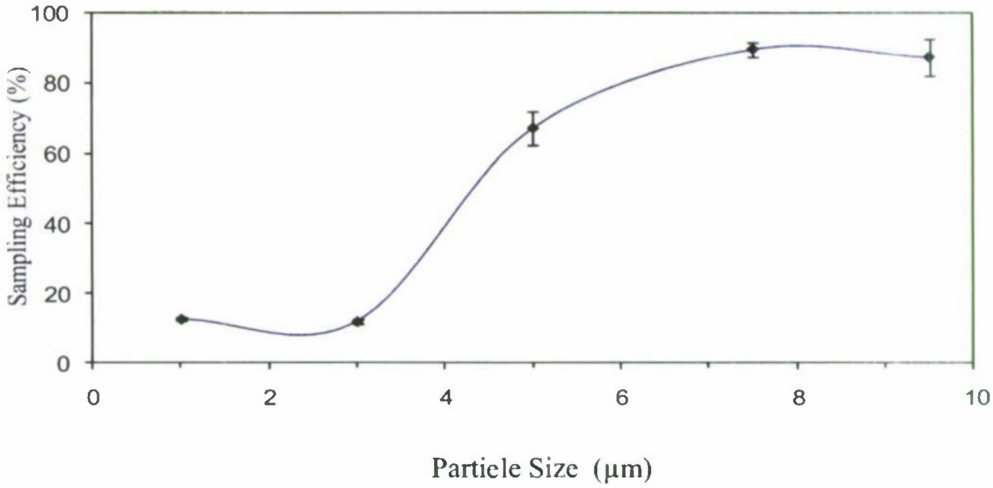
Sandia National Laboratories, Albuquerque, NM

Air is drawn into the Sandia collector through a long externally mounted inlet tube, through a moveable internal inlet, after which the airstream encounters a reel-fed polycarbonate membrane type collection filter. The filter where particles are collected is contained on a reel, which automatically advances to the collection area under the inlet where a rubber gasket presses against it, achieving a seal to contain and direct the sampled air through the filter. After the sampling period has ended, the collection filter is automatically advanced, and two mylar tapes are fed to emplace on the top and bottom of the filter, creating a "sandwich" with the collection filter in the middle of the two mylar films. This test was started in May 2003.



Measured (at inlet) air sampling rate (L/min)	112
Dimensions (in.) Main box - L x W x H Main box w/inlet & stand	 24 x 20 x 9 24 x 33 x 31
Weight (lb with stand)	88
Power (W) Voltage (V) Current (A)	292 117.5 2.8

Particle Type	Particle Size (μm)	Sampling Efficiency (%)
PSL	1	12.7 ± 0.4
	3	12.0 ± 0.7
	5	67.3 ± 4.9
Fluorescent oleic acid	7.5	89.6 ± 2.1
	9.5	87.3 ± 5.3



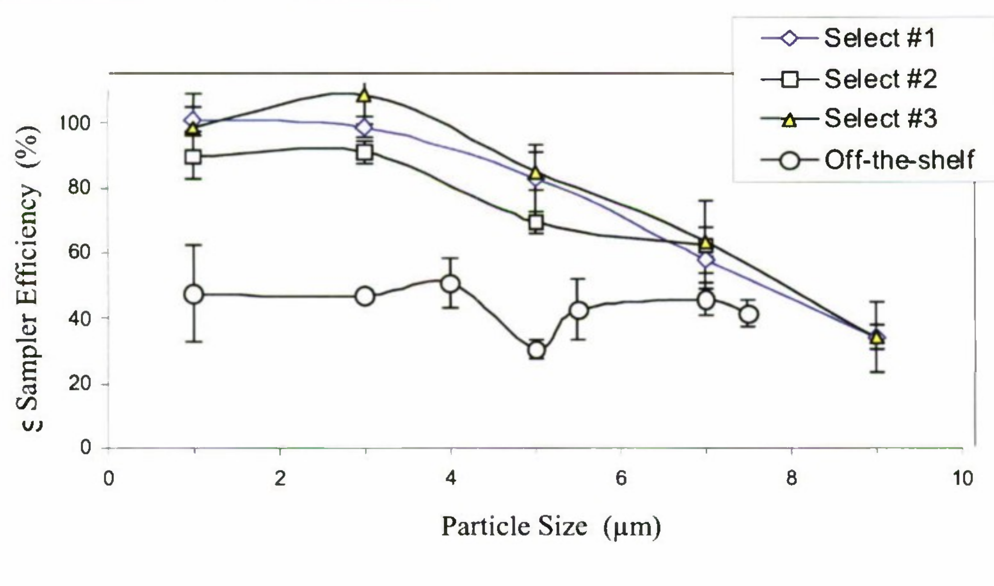
APPENDIX 8

SKC BioSampler® - Aerosol Sampler

SKC Inc., Eighty-Four, PA

The SKC Biosampler® is a more recent addition to the liquid impinger type collectors, and is designed to reduce stress on biological organisms, thus improving culture analysis results. It uses a basic collection mechanism which is inertial impaction of the aerosol particles into a liquid. Although it is similar to other liquid impinger collection devices, the SKC BioSampler® has a different jet design to reduce the extreme turbulence, which is prone to damage biological cells. The jet design is different because there are three jets instead of one, and the jets are positioned to direct the aerosol at a tangential angle to the water. This angle is designed to minimize damage to organisms from the extreme turbulent forces of some impinger devices. This test was started in April 2003.

Designed airflow rate (L/min)	12.5
Measured airflow rate (L/min)	12.5
Dimensions (in.) Height Diameter	 8.5 1.5
Weight (oz)	5.9
Power	uses external pump



APPENDIX 9

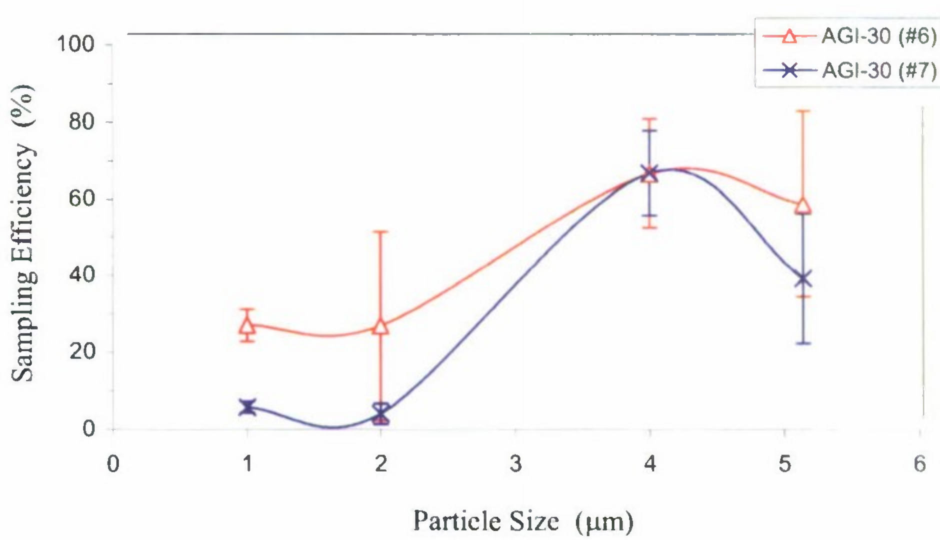
AGI-30 Impinger

ACE Glass Inc., Vineland, NJ

This is an aerosol sampler that uses impaction and impingement to collect particles into liquid. The AGI-30 draws air through an inlet curved to simulate the upper respiratory tract and collects larger particles in the curve. Air is then passed through the inlet to a single jet, and into 20 mL (initially) of a liquid medium for collection and retention of aerosol particles. The jet is a critical component for proper functioning of the unit. If it is damaged (e.g., chipped), it may alter the airflow dynamics, thus affecting collection into the liquid. The unit is designed to operate optimally with a sonic airflow rate of 12.5 L/min. Sampling time should be selected to minimize evaporation of the liquid. This test was started in April 2003.

Number of units tested	2
Designed airflow rate (L/min)	12.5
Measured airflow rate at inlet (L/min)	average of two samplers 12.5
Physical parameters (without pump): Weight, oz (g) Height, in. (cm) Diameter, in. (cm)	 4.7 10.75 1.5

Particle material	Particle Size (μm)	Sampling Efficiency (%)	
		AGI-30 (#6)	AGI-30 (#7)
PSL	1	27.0 ±4.2	5.8 ±1.5
PSL	2	26.9 ±24.5	4.1 ±2.7
Fl. oleic	4	66.6 ±14.3	66.8 ±11.1
PSL	5.2	58.7 ±24.3	39.2 ±17.0

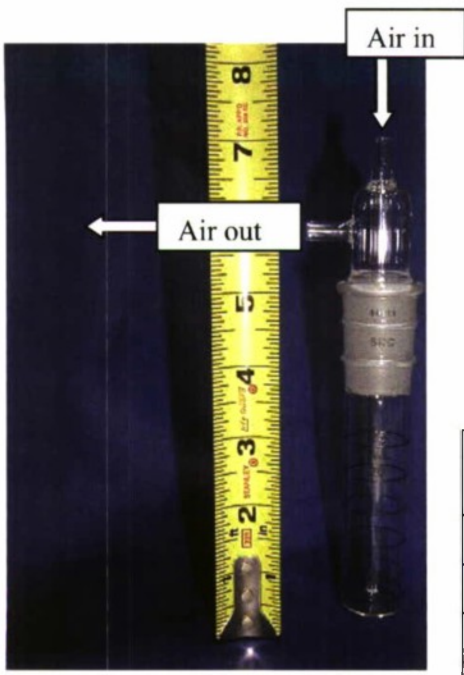


APPENDIX 10

Midget Impinger

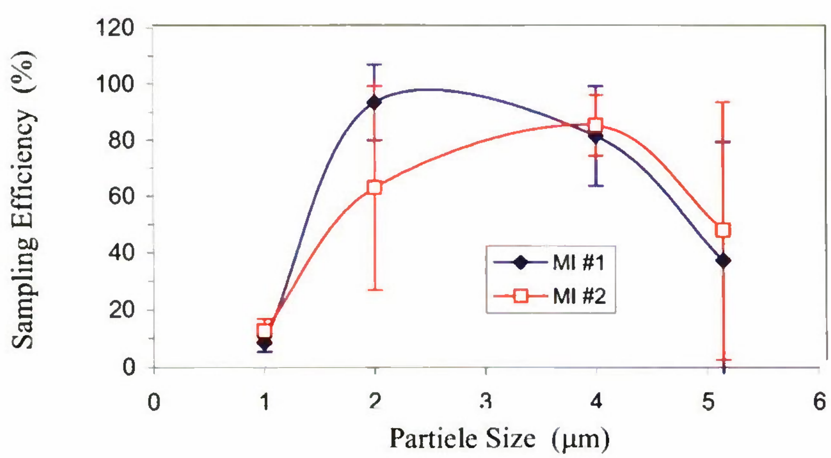
SKC Ine., Eighty-Four, PA

This is an aerosol sampler that uses impaction and impingement to eolleet particles into liquid. The Midget Impinger draws air through a straight inlet. Air is then passed through the inlet to a single jet and into 20 mL (initially) of a liquid medium for eolleetion and retention of aerosol partieles. Like other impingers, the jet is a eritieal eomponent for proper funetioning of the unit. If it is damaged (e.g., ehipped), the Impinger may alter the airflow dynamies, thus affecting eolleetion into the liquid. The unit is designed to operate optimally with a sonic airflow rate of 1 L/min; however, aberrations in jet orifiee may cause the actual sonie flow to be more or less than 1 L/min. Sampling time should be seleeted to minimize evaporation of the liquid. This test was started in April 2003.



Number of units tested	2
Designed airflow rate (L/min)	1
Measured airflow rate at inlet (L/min)	1
Physical parameters (without pump): Weight (oz)	2.7
Height (in.)	7.25
Diameter (in.)	0.87

Test material	Particle Size (µm)	Sampling Efficiency (%)	
		Impinger (#1)	Impinger (#2)
PSL	1	8.6 ± 3.2	12.6 ± 4.33
PSL	2	93.5 ± 13.5	63.2 ± 36.2
Fl. oleic	4	81.6 ± 17.7	85.4 ± 10.8
PSL	5.2	37.3 ± 42.1	38.2 ± 45.5

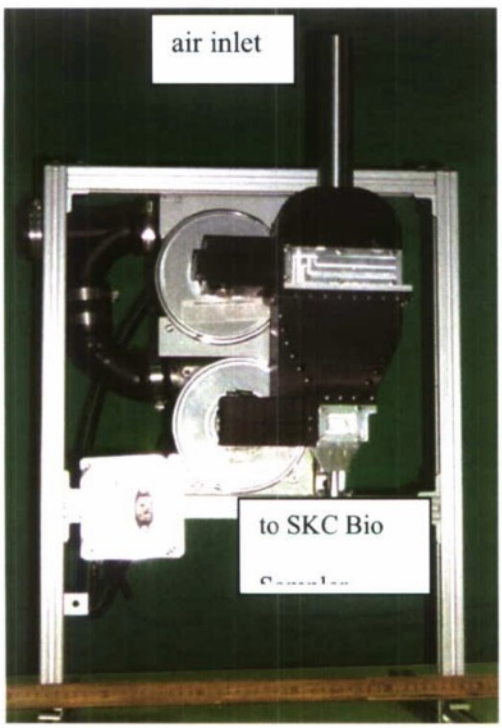


APPENDIX 11

Two Stage MicroVIC® Aerosol Concentrator Connected to an SKC BioSampler® (ECBC-TN-014)

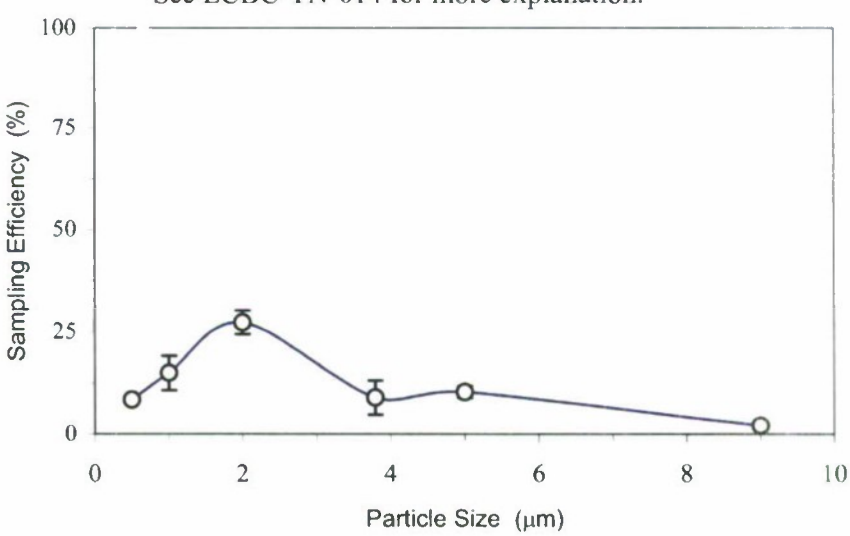
MesoSystems Technology Inc., Kennewick, WA

This aerosol sampler concentrates particles from a 400 L/min flow into a 12.5 L/min minor flow. Air enters the sampler through the opening on top at a flow rate of 400 L/min, and the concentrated minor airflow of 12.5 L/min goes to a SKC BioSampler® for collecting particles into liquid. This test was started in May 2002.



Designed airflow rate (L/min)	400
Measured air sampling rate (L/min)	403
Concentrator dimensions (in.) Length Width Height	Concentrator alone 19 9 29.5
Power consumption (W)	MicroVIC® alone - 323 MV with SKC - not measured
Particle size (μm) 0.5 1 2 3.8 5 9	Sampling efficiency (% ±1 std dev) 8.5 ± 0.6 15.0 ± 14.2 27.3 ± 2.9 9.0 ± 4.1 10.4 ± 1.4 2.1 ± 0.1

See ECBC-TN-014 for more explanation.

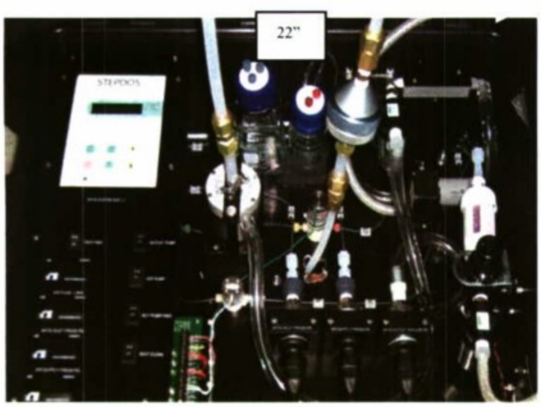


APPENDIX 12

Aerosol To Hydrosol Transfer System (AHTS) Version 1.1

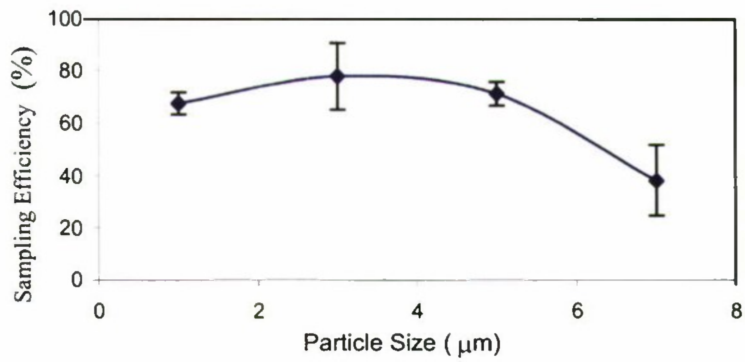
Texas A&M University, College Station, TX

This sampler serves as the final collection stage for an aerosol concentrator. The AHTS Version 1.1 is the size of a medium suitcase that serves to transfer particles from the air to a liquid medium. The unit operates by impacting air onto a thin layer of liquid located on top of a porous metal substrate. Liquid (water with surfactant) flows through small holes in the porous metal cylinder and encounters the aerosol. The hydrosol (solution containing aerosol particles) is pumped to a collection container. This test was started in May 2004.



Designed air sampling rate (L/min)	1
Measured airflow rate (L/min)	1
Liquid flow rate (mL/min)	0.33
Dimensions (in.) Length Width Height	 23 9 18
Weight (lb)	25
Power (W) Voltage (V) Current (A)	27 119 0.45

Particle Type	Particle Size (μm)	Sampling Efficiency (%)
PSL	2 3	67.4 ± 4.2 77.8 ± 12.7
Fluorescent oleic acid	5 7	71.1 ± 4.5 38.1 ± 13.5

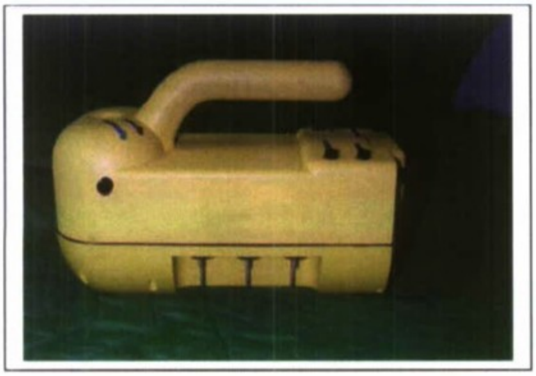


APPENDIX 13

BioCapture™ BT-500 Aerosol Sampler (ECBC-TR-249)

MesoSystems Technology Inc., Kennewick, WA

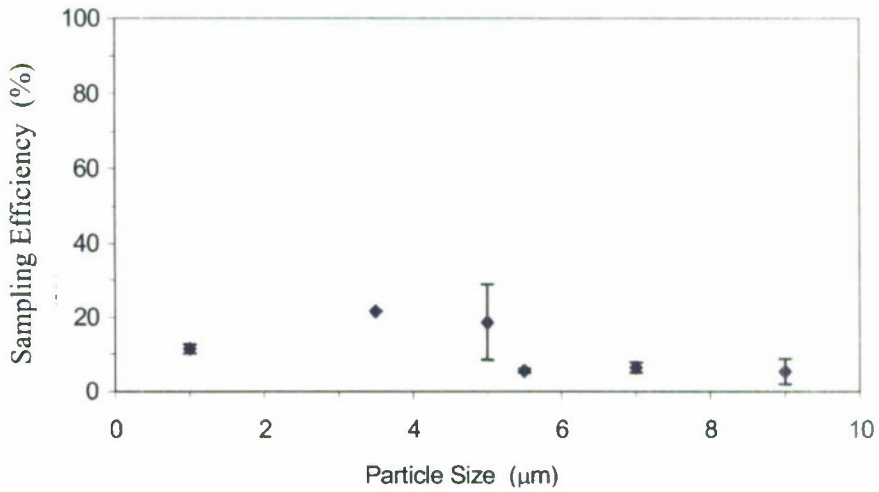
The BioCapture™ BT-500 aerosol sampler impacts particles onto a wet rotating surface. This is a portable, light weight, battery operated 150 L/min sampler. The sampler requires liquid cartridges that contain prewash, sample collection, and sterilization liquids that can be obtained from the manufacturer. The inlet is a 1 $^{3}/_{16}$ in. diameter opening that has a screen to prevent large particles and insects from entering the sampler. This test was started in January 2000.



Designed airflow rate (L/min)	150
Measured air sampling rate (L/min)	150
Dimensions (in.) Length Width Height	 12 6 8
Weight (lb)	9
Power Supply	12 V, 3 Ah re-chargeable battery

Particle Type	Particle Size (μm)	Concentration Efficiency (%)
PSL	1 3.5	11.4 ± 1.2 21.6 ± 0.04
Fluorescent oleic acid	5 5.5 7 9	18.6 ± 10.2 5.6 ± 0.5 6.5 ± 1.4 5.3 ± 3.3

See ECBC-TR-249 for more explanation.



APPENDIX 14

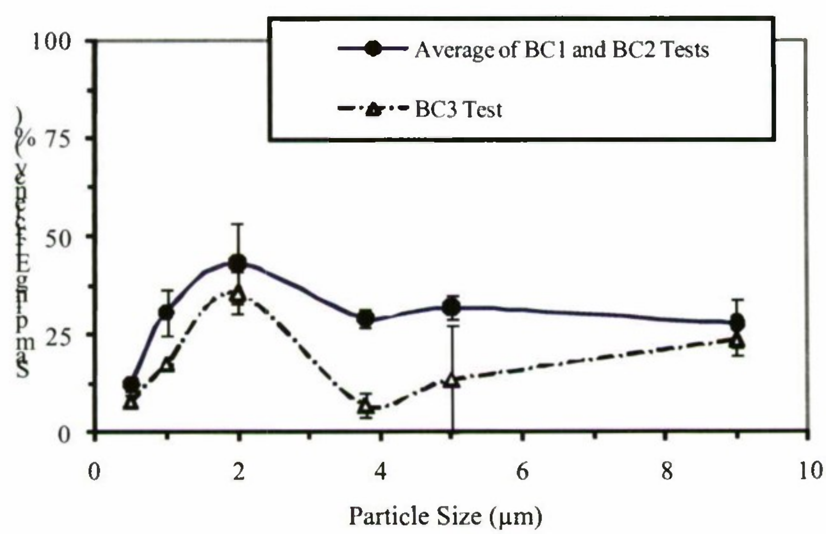
BioCapture™ BT-550 Aerosol Sampler (ECBC-TN-014)

MesoSystems Technology Inc., Kennewick, WA

The BioCapture™ (BC) BT-550 aerosol sampler impacts particles onto a wet rotating surface. This is a portable, light weight, battery operated 150 L/min sampler. It is identical to the BioCapture™ BT-500, except it is able to accommodate detection strips. The sampler uses liquid-filled cartridges containing sample collection and decontamination liquids that can be obtained from the manufacturer. This test was started in May 2002.

Designed airflow rate (L/min)	150	
Measured air sampling rate (L/min)	150	
Overall dimensions (in.)		
Length	12	
Width	6	
Height	8	
Power (W)	Battery operated	
Weight (lb)	10	
Particle size (µm)	Sampling efficiency (%) ±1 Std. Dev.	
	Ave. of BC1 & BC2	BC3
0.5	12.4 ± 2.0	8.0 ± 1.4
1	30.8 ± 5.9	17.7 ± 0.2
2	38.1 ± 1.1	33.2 ± 2.2
3.8	29.2 ± 2.3	7.0 ± 2.9
5	32.0 ± 3.2	13.6 ± 14.1
9	27.8 ± 6.1	24.0 ± 4.1

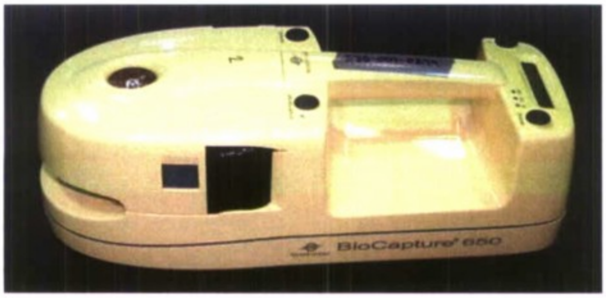
See ECBC-TN-014 for more explanation.



APPENDIX 15

BioCapture™ 650 Bioaerosol Sampler (ECBC-TN-029)
MesoSystems, Albuquerque, NM

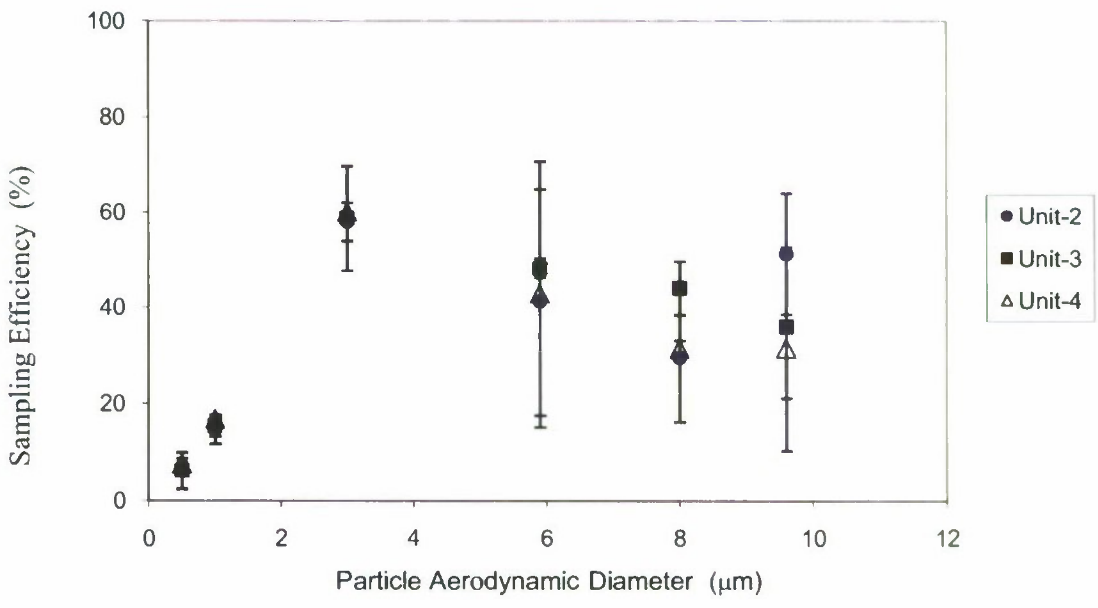
The BioCapture™ 650 is a portable, battery operated, bioaerosol sampler. This sampler uses the rotating impactor technology that captures particles onto a dry surface. At the end of sampling, the particles are washed off by a buffer solution. The advantage of this unit over the earlier BioCapture™ models is the disposable sampling head that contains the impaction surface and liquid consumables, eliminating the cleaning between samples. This test was started in November 2005.



Designed airflow rate (L/min)	200
Measured airflow rate (L/min)	192 - 194
Dimensions (in.)	5 x 6 x 14
Weight without the battery (lb)	7.5

Particle Size (μm)	Particle Type	Temperature	BC 650		
			Unit-2	Unit-3	Unit-4
0.5	PSL	Room	6.5 ±1.4	6.2 ± 3.8	7.6 ± 1.1
1.0	PSL	Room	14.7 ±3.0	15.4 ± 2.2	16.8 ± 0.2
3.0	PSL	Room	58.0 ±4.1	58.7 ± 11.0	60.0 ± 0.1
5.9	Oil	Room	41.2 ±23.8	48.2 ± 2.1	42.9 ± 27.9
8.0	Oil	Room	29.5 ±13.3	44.0 ± 5.7	31.3 ± 1.7
9.6	Oil	Room	51.3 ±12.8	35.9 ± 14.8	31.4 ± 21.2
5.9	Oil	Cold	38.2 ±13.1	36.4 ± 8.0	44.6 ± 14.6
5.9	Oil	Hot	44.1 ±10.6	34.6 ± 10.0	51.3 ± 4.9

See ECBC-TN-029 for more explanation.



APPENDIX 16

BioBadge® Aerosol Sampler (ECBC-TN-024)

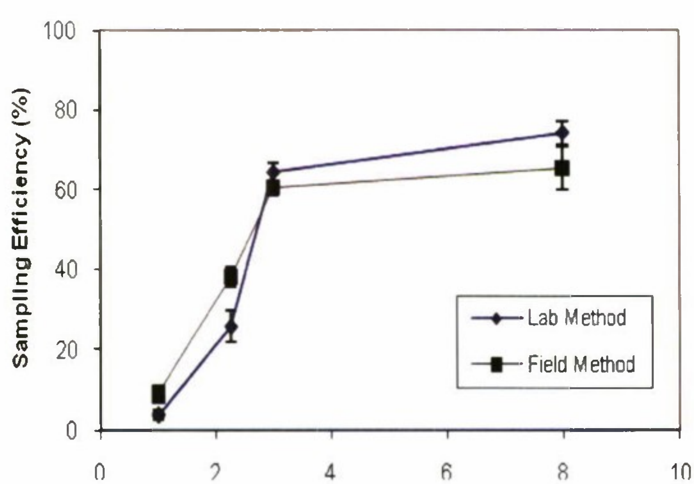
MesoSystems Technology, Inc.,
Kennewick, WA

The BioBadge® is a small battery operated sampler that can be used as a personal sampler. This sampler uses the MesoSystems's rotating impactor/impeller technology to impact particles onto the impeller, which is used to move air as well as to collect particles. The particles are collected dry and then removed into a liquid by either the Laboratory (sonication) or Field Method (handshaking). This test was started in January 2000.

Designed airflow rate (L/min)	35
Measured airflow rate (L/min) of three samplers #11 #12 #13	 31.9 37.4 33.3
Dimensions (in.) Length Width Height	 5.5 2.75 1.5
Weight (lb)	0.55
Sample output	5
Power	battery operated

Particle Size (µm) (Type)	Sampling Efficiency by Recovery Method	
	Lab	Field
1 (PSL)	4.0 ± 0.9	9.3 ± 1.1
2.3 (PSL)	25.7 ± 4.0	38.1 ± 2.5
3 (Fl. Oleic Acid)	64.4 ± 2.3	60.5 ± 1.9
8 (Fl. Oleic Acid)	74.3 ± 3.0	65.5 ± 5.4
1 (Organism-Bg)	3.78 ± 1.2	8.43 ± 0.9

See ECBC-TN-024 for more explanation.



Particle Size (µm)

APPENDIX 17

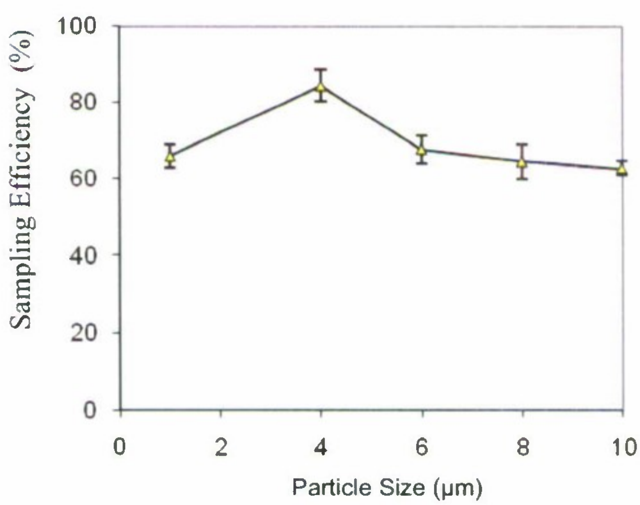
Portable High Throughput Liquid-Assisted Air Sampler (PHTLAAS™) #3 Air Sampler (ECBC-TR-267)

Zaromb Research Corp., Hinsdale, IL

The PHTLAAS™ #3 aerosol sampler is a portable, light weight, high volume sampler that has a wetted wall cyclone for aerosol collection. The sampler is packaged in a suitcase with a handle for easy carrying. The results shown below are for a PHTLAAS™ with a slit inlet and liquid re-circulation. This test was started in January 2000.

Measured air sampling rate (L/min)	317
Dimensions (in.)	
Length	14
Width	8
Height	18
Weight (lb)	20
Liquid sample volume (mL)	35.3 ± 3.5
Power (W)	85.3
Voltage (V)	123.6
Current (A)	1.1
Particle Size (µm)	Sampling Efficiency (%) ±1 Std. Dev.
1	65.7 ± 3.0
4	84.3 ± 4.2
6	67.5 ± 3.7
8	64.3 ± 4.6
10	62.5 ± 1.9

See ECBC-TR-267 for more explanation.



APPENDIX 18

PHTLAAS™ APAS 2 #4 Air Sampler (ECBC-TN-30)

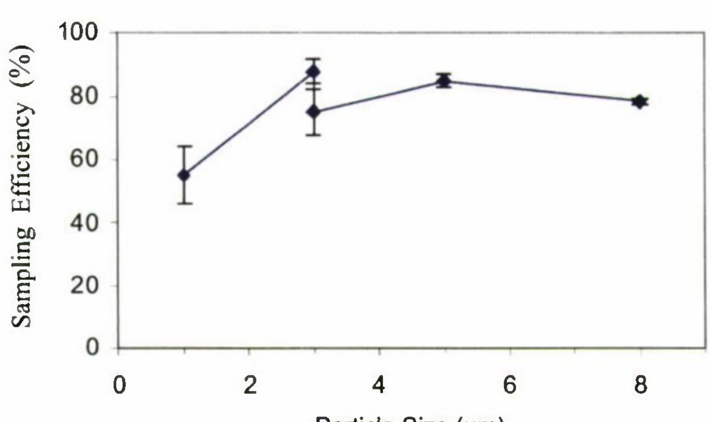
(Portable High Throughput Liquid-Assisted Air Sampler)

Zaromb Research Corp., Hinsdale, IL

The PHTLAAS™ aerosol sampler is a portable, light weight, high volume sampler that has a wetted wall cyclone for aerosol collection. The sampler is packaged as a lightweight cylinder to which a strap is attached for easy carrying. The results shown below are for a PHTLAAS™ with slit inlet and liquid re-circulation. This test was started in September 2004.

Air sampling rate (L/min)	305.9
Liquid sample input, mL Output, mL	25 18 in 10 min
Dimensions (in.) Height Diameter	 20 6
Power (W) Voltage (V) Current (A)	49 11.5 4.18
Particle Size (Type) (µm)	Sampling Efficiency (%) +1 std dev
1 (PSL) 3 (PSL) 3 (Fl. Oleic Acid) 5 (Fl. Oleic Acid) 8 (Fl. Oleic Acid)	55.1 ± 8.8 87.7 ± 3.8 75.0 ± 7.2 84.6 ± 2.1 78.2 ± 1.0

See ECBC-TN-30 for more explanation.



APPENDIX 19

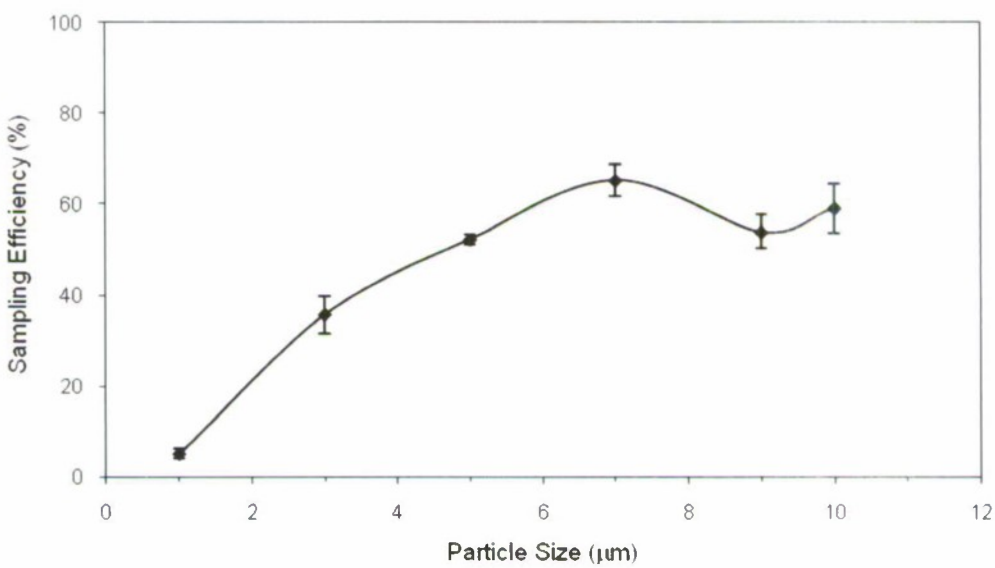
Smart Air Sampler System, SASS 2000$^{\text{Plus®}}$ (ECBC-TN-021)

Research International, Woodinville, WA

The SASS 2000$^{\text{Plus®}}$ is a wetted wall cyclone sampler that can be easily carried by a single person. The air sampler is microcontroller based and can function either as a stand-alone unit or be linked to other sampling, detection, or communication systems via an RS-232 link. This system continuously recycles liquid to concentrate the sample. Water is added to the cyclone from the liquid pouch to compensate evaporation. The testing results provided below are for a SASS operated manually as a stand-alone unit on AC power. This test was started in October 2003.

Designed airflow rate (L/min)	265
Measured airflow rate (L/min)	307.4
Sample Volume (mL)	5.0 ± 0.45
Dimensions (in.)	
Height	13
Diameter	8
Weight with battery (lb)	9
Power (W)	14.4
Particle Size (μm)	Sampling Efficiency (%) ±1 Std. Dev.
1	5.0 ± 1.1
3	35.8 ± 4.1
5	52.3 ± 1.2
7	65.1 ± 3.4
9	53.9 ± 3.7
10	60.0 ± 5.4

See ECBC TN-021 for more explanation.

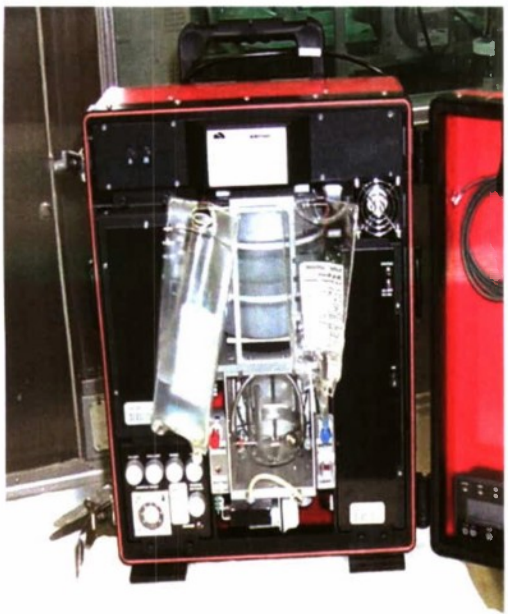


APPENDIX 20

SpinCon - Aerosol Sampler (ECBC-TN-027)

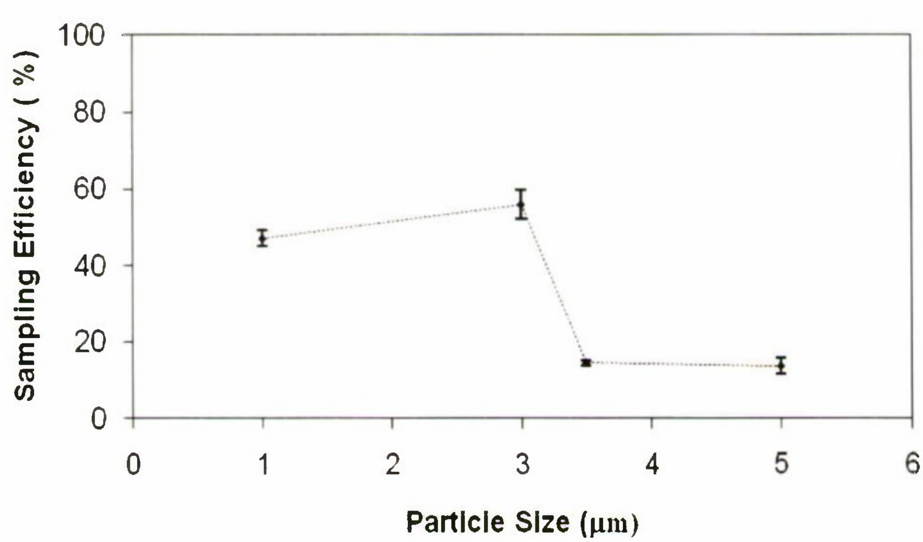
Midwest Research Inst., Kansas City, MO

The SpinCon is a portable, light weight, high volume sampler. It has a wetted wall cyclone (or a contactor) for aerosol collection. The sampler is packaged in a suitcase with a handle for easy carrying. This test was started in May 2005.



Designed airflow rate (L/min)	400 or 450
Measured airflow rate (L/min)	457
Dimensions (in.)	
Length	15
Width	10
Height	19
Weight (lb)	46
Sample volume (mL)	5.9 - 11.5
Power (W)	approx. 283
Particle Size (μm)	Sampling Efficiency (%) ±1 Std. Dev.
1	47.3 ± 2.1
3	56.1 ± 3.9
3.5	14.6 ± 0.6
5	13.8 ± 2.2

See ECBC-TN-027 for more explanation.



APPENDIX 21

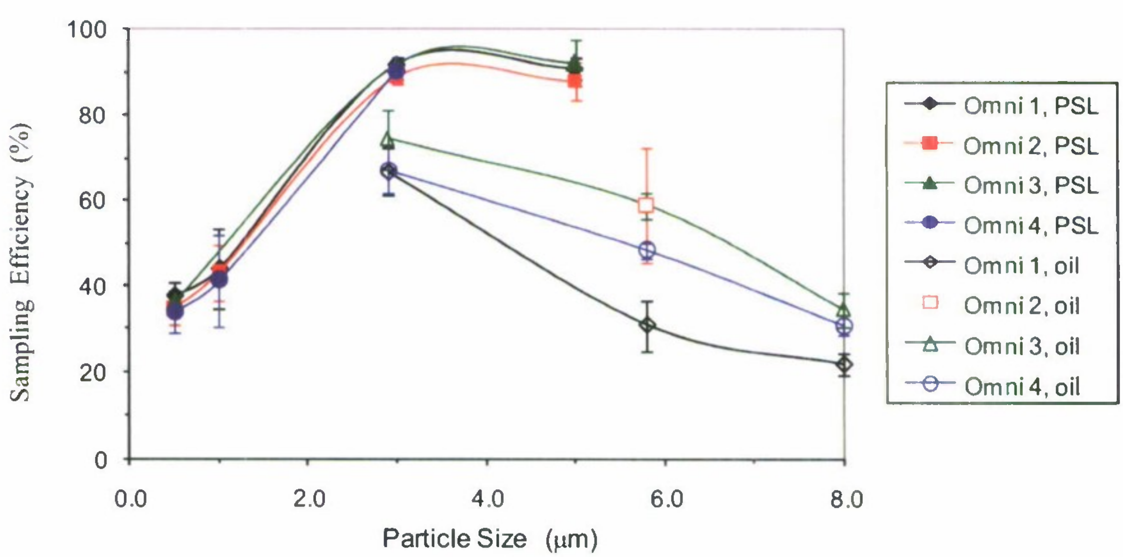
Omni 3000 (ECBC-TN-028)
Sceptor Industries, Inc., Kansas City, MO

The Omni 3000 aerosol sampler is a non-traditional wetted wall cyclone (contactor). Air enters the contactor through two narrow slits. The unit retains the water in the contactor and does not produce a continuous liquid output stream. A liquid pouch is placed inside the sampler, and it adds liquid as water evaporates during sampling. This test was started in February 2006.

Designed airflow rate (L/min)	300
Measured airflow rate (L/min)	268 - 286
Dimensions (in.)	L=8.5; W=7; H=17
Weight (lb)	14 (without battery) 21 (with battery)
Sample Volume (mL)	10.7 - 12.0
Power (W)	74 - 92

Particle Size (μm)	Particle Type	Sampling Efficiency (%)			
		Omni-1	Omni-2	Omni-3	Omni-4
0.5	PSL	37.8 ± 2.7	34.7 ± 3.7	36.1 ±1.9	34.0 ± 5.0
1.0	PSL	44.0 ± 9.3	43.1 ± 6.4	Not run	41.2 ± 10.7
3.0	PSL	91.7 ± 1.9	89.1 ± 1.6	91.8 ± 0.7	90.6 ± 2.5
5.0	PSL	90.8 ± 2.7	88.0 ± 4.3	92.3 ± 5.2	Not run
2.9	Oil	66.6 ± 5.6	Not run	74.3 ± 7.1	67.1 ± 5.6
5.8	Oil	30.8 ± 5.9	58.8 ±	58.8 ± 3.0	48.3 ± 1.8
8.0	Oil	21.7 ± 2.6	13.4	34.4 ± 4.0	30.8 ± 2.3

See ECBC-TN-028 for more explanation.



APPENDIX 22

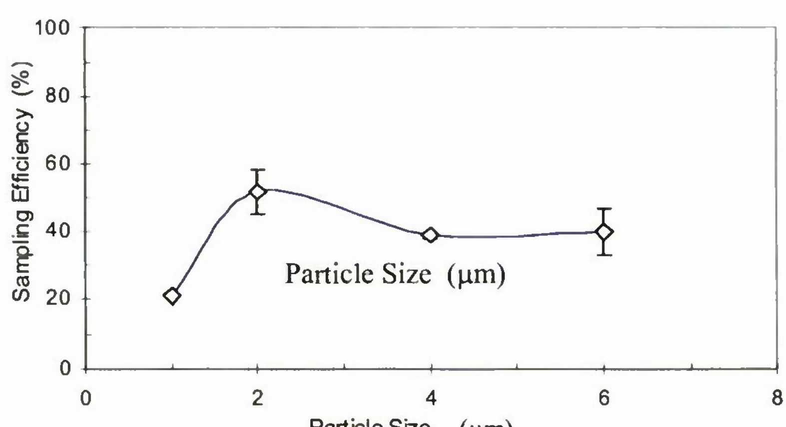
BioGuardian® 1.02 Aerosol Sampler (ECBC-TN-013)

InnovaTek, Richland, WA

BioGuardian® 1.02 has one wetted wall cyclone for aerosol collection. The collection mechanism is by inertial impaction. The air inlet is a rectangular opening that is opened to the atmosphere. The individual cyclones (BG4, 12.02, and 12.03) are the same in all the Bioguardian® systems listed in this report. This test was started in June 2002.

Number of Cyclones	1
Designed airflow rate (L/min)	90
Measured airflow rate (L/min)	88
Sample Volume (mL) Designed Measured	 10 7.7 ± 0.5
Dimensions (in.) Length Width Height	 11.8 11.0 17.3
Weight (lb)	17
Power (W)	57.5
Particle Size (µm)	Sampling Efficiency (%) ±1 Std. Dev.
1	21.2 ± 0.6
2	51.5 ± 6.4
4	38.8 ± 0.9
6	39.9 ± 6.9

See ECBC-TN-013 for more explanation.

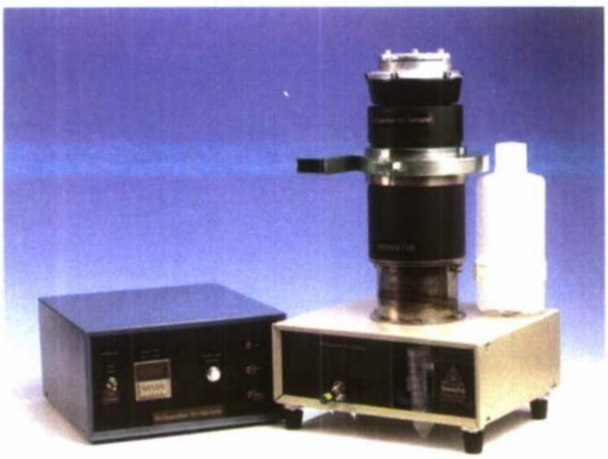


APPENDIX 23

BioGuardian® 4.02 Aerosol Sampler (ECBC-TN-013)

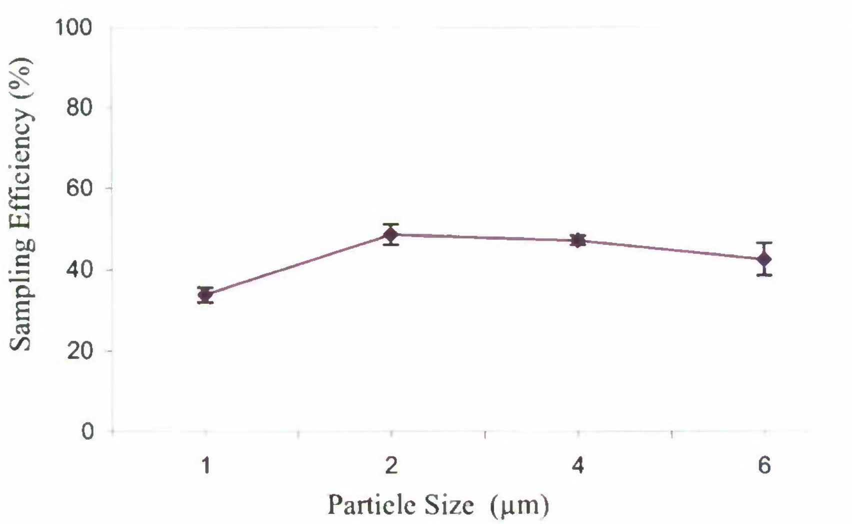
InnovaTek, Richland, WA

This sampler has four wetted wall cyclones for aerosol collection. Individual cyclones in all BioGuardian® samplers have the same design. This test was started in June 2002.



Number of Cyclones	4
Designed airflow rate (L/min)	350
Measured airflow rate (L/min)	351
Sample Volume (mL) Designed Measured	 10.0 11.6 ± 1.3
Dimensions (in.) Length Width Height	 12 10 18
Weight (lb)	32.5
Power (W)	137
Particle Size (µm)	Sampling Efficiency (%) ±1 Std. Dev.
1	33.8 ± 1.8
2	48.6 ± 2.5
4	47.4 ± 1.2
6	42.8 ± 4.0

See ECBC-TN-013 for more explanation.

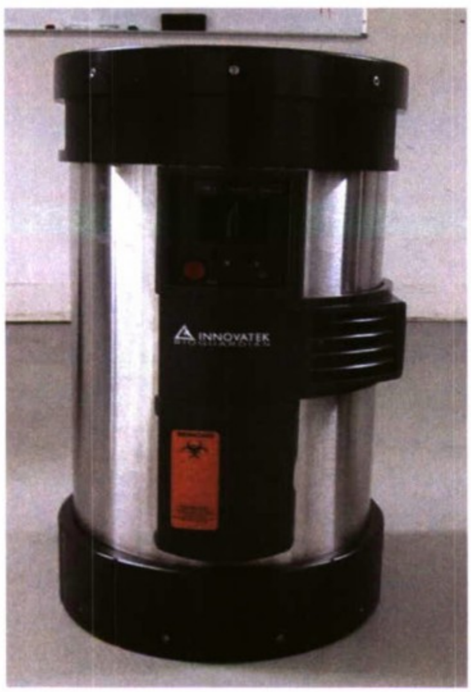


APPENDIX 24

BioGuardian® 12.02 Aerosol Sampler (ECBC-TN-013)

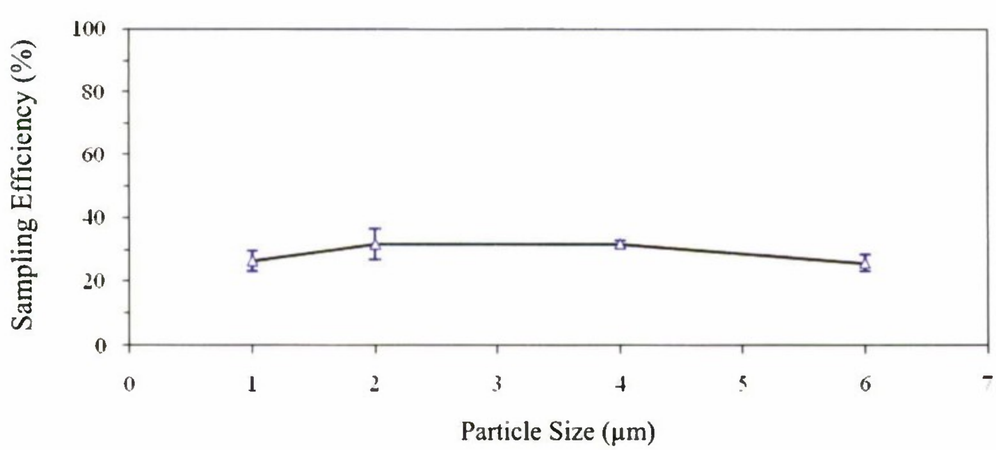
InnovaTek, Richland, WA

The BioGuardian® 12.02 has 12 wetted wall cyclones for aerosol collection. There is a pre-separator to remove large particles before the air enters the cyclones. This test was started in June 2002.



Number of Cyclones	12
Designed airflow rate (L/min)	1,100
Measured airflow rate (L/min) (measured at InnovaTek)	1,000
Sample Volume (mL)	12.6 ± 2.3
Dimensions (in.) Height Diameter	25.0 14.5
Weight (lb)	> 75
Power (W)	421
Particle Size (μm)	Sampling Efficiency (%) ±1 Std. Dev
1	26.5 ± 3.4
2	31.7 ± 4.7
4	31.9 ± 1.2
6	25.8 ± 2.7

See ECBC-TN-013 for more explanation.



APPENDIX 25

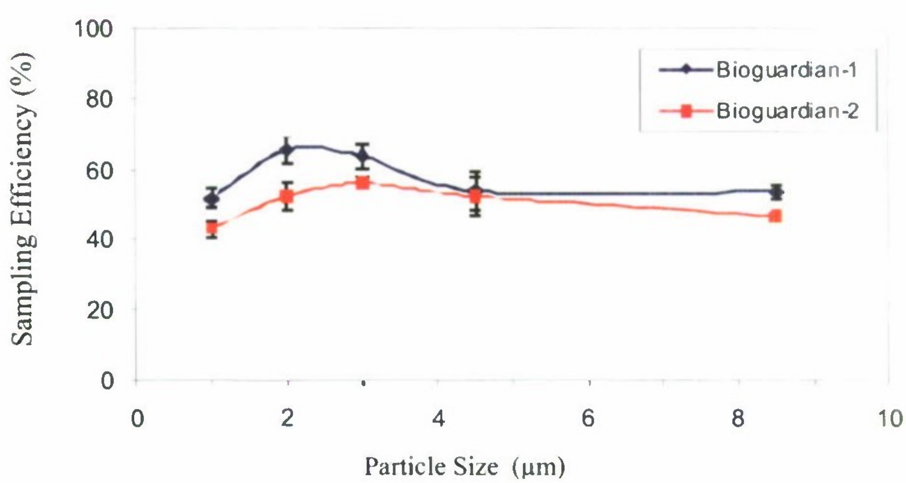
BioGuardian® 12.03 Aerosol Sampler (ECBC-TN-023)

InnovaTek, Richland, WA

The BioGuardian® BG12.03 has 12 wetted wall cyclones for aerosol collection, and it is improved from the BG12.02 in that it has a better finished collection surface in the cyclone. This is a programmable sampler that can sample from 5 s to 24 h, and the computer can adjust the liquid input to the cyclone. There is a pre-separator to remove large particles before the air enters the cyclones. This test was started in October 2003.

	Test Unit 1	Test Unit 2
Number of Cyclones	12	12
Designed airflow rate (L/min)	1,000	1,000
Measured airflow rate (L/min)	896.4	824.1
Dimensions (in.) Diameter Height	14.5 25	14.5 25
Weight - estimate (lb)	70	70
Sample Volume (mL)	28.9 ± 2.02	25.07 ± 1.74
Power (W)	378	378
Particle Size (μm)	Sampling Efficiency (% ± 1 Std. Dev.)	Sampling Efficiency (% ± 1 Std. Dev.)
1	51.8 ± 2.9	43.3 ± 2.3
2	65.6 ± 3.6	52.4 ± 4.0
3	63.8 ± 3.3	56.1 ± 1.4
4.5	53.9 ± 5.5	52.4 ± 5.8
8.5	53.6 ± 1.7	46.8 ± 1.2

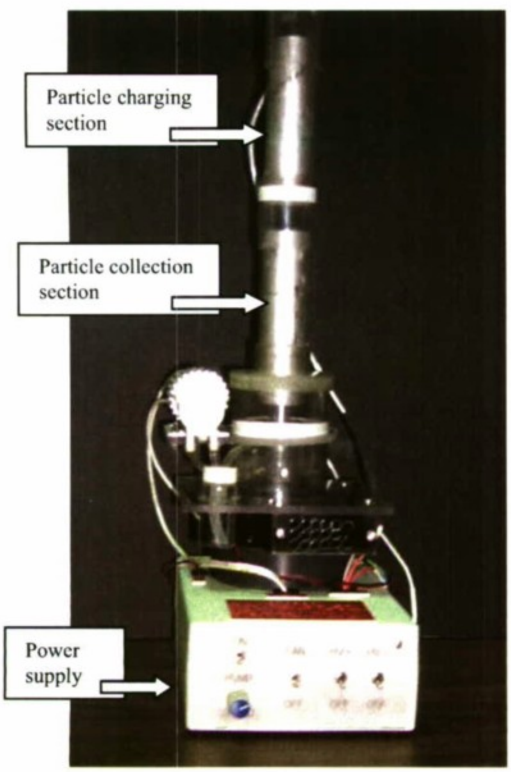
See ECBC-TN-023 for more explanation.



APPENDIX 26

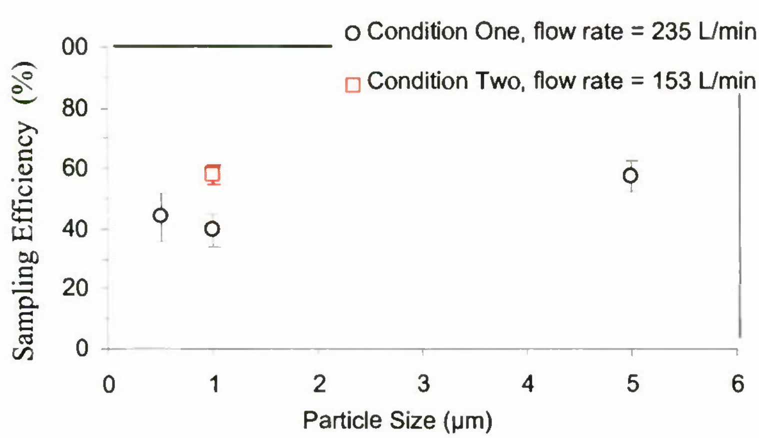
Aerosol to Liquid Particle Extraction System (ALPES) #1 (ECBC-TN-017)
Savannah River Technology Center, Aiken, SC

The ALPES sampler uses the principle of charging the particles first and then collecting them using the opposite charge on the collection surface. In the first half of the tube, the particles are charged; in the second half, they are collected. In the particle charging region (ionization section), a positive high voltage wire runs in the center of the tube. In the collection region, a wetted negative high voltage collection surface is in the center to collect the particles. A water pump delivers the liquid to the top of the collection surface, and the liquid drains back to the bottom from where it is pumped to the top again. This test was started in September 2003.



Characteristics	ALPES #1	
	Condition One	Condition Two
Designed airflow rate (L/min)	250	
Airflow rate measured at inlet (L/min)	235	153
Electrical Properties, measured at ECBC Power (W) Voltage (V) Current (A)	 24.4 118.5 0.39	not measured
Weight (lb)	Not Measured	
Dimensions (in.) Inlet Cylinder Diameter Height Box Width Length	 Not Measured 22 6 10	no change
Aerodynamic Particle Size (μm)	Sampling Efficiency (%) ± one standard deviation	
0.5 1 5	44.0 ± 8.0 39.6 ± 5.6 57.4 ± 5.1	58.1 ± 3.2

See ECBC-TN-017 for more explanation.

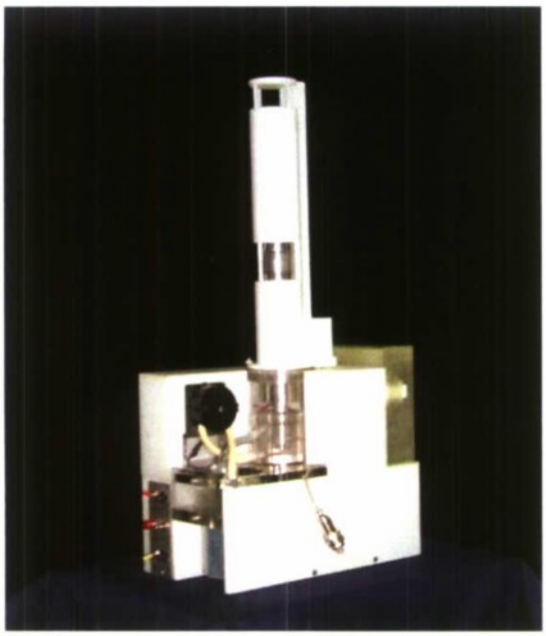


APPENDIX 27

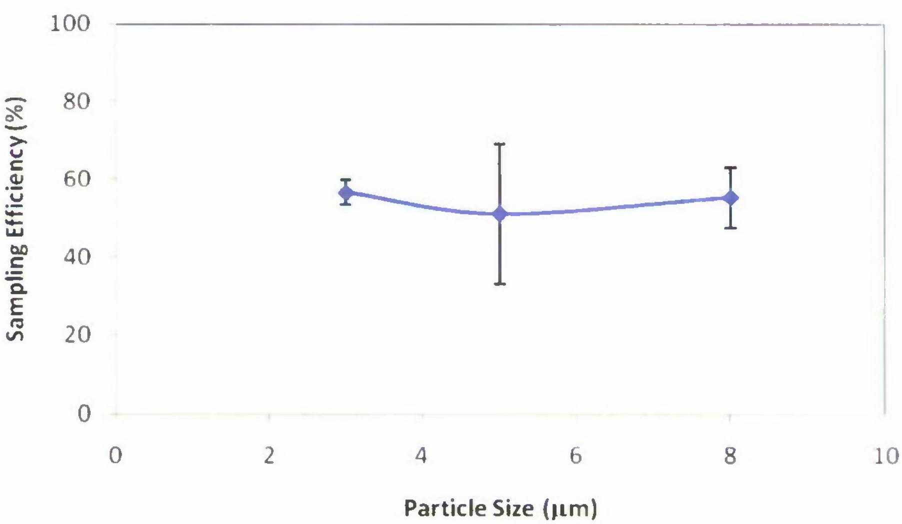
Aerosol to Liquid Particle Extraction System (ALPES) #2

Savannah River Technology Center, Aiken, SC

This sampler uses the principle of charging the particles first and then collecting them using the opposite charge on the collection surface. In the first half of the tube, the particles are charged; in the second half, they are collected. In the particle charging region (ionization section), a positive high voltage wire runs in the center of the tube. In the collection region, a wetted negative high voltage collection surface is in the center to collect the particles. A water pump delivers the liquid to the top of the collection surface, and the liquid drains back to the bottom where it is pumped to the top again. This test was started in September 2004.



Measured airflow rate (L/min)	286.7
Dimensions (in.) Length Width Height	 14 6.5 21
Weight (lb)	14
Sample volume (mL)	11.8 – 24.1
Power (W) Voltage (V) Current (A) PF	33.4 121.30 0.47 0.59
Particle Size (μm) 3 5 8	Sampling Efficiency (%) 56.6 ± 3.2 51.2 ± 17.9 55.4 ± 7.8



APPENDIX 28

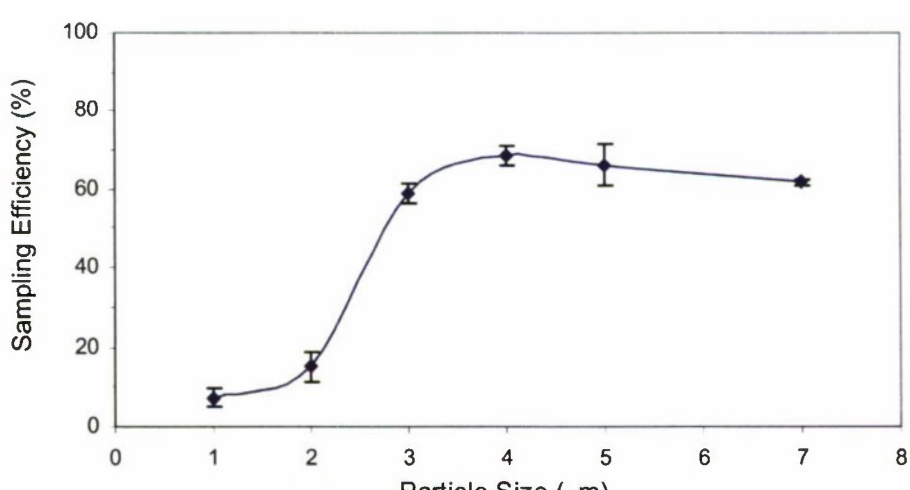
Microbial Air Monitoring System MAS-100® (ECBC-TN-019)

EM Science, Gibbstown, NJ

The MAS-100® is based on the principle of the Andersen N6 single stage viable impactor, using inertial impaction as the collection mechanism. It operates by aspirating air through a 400-hole perforated entry plate onto a Petri dish containing biological collection media (i.e., agar), at an airflow rate of 100 L/min. The MAS-100® can be used either in manual, in programmable modes, or with a personal computer. Design specifications indicate the MAS-100® has the capacity to aspirate approximately 50,000 L of air with a fully charged battery (at 100 L/min, that is approximately 8 h 20 min), although a 10 min maximum per petri dish sampling is recommended to avoid dehydration of the agar. This test was started in March 2002.

Designed airflow rate (L/min)	100
Measured airflow rate (L/min)	100
Dimensions (in.) Height Diameter	 10.25 4.3
Weight (lb)	4.85 (w/battery)
Power - AC (W)	36 or battery
Particle Size (μm)	Sampling Efficiency (%) ± 1 std dev
1	7.3 ± 2.2
2	15.2 ± 3.8
3	58.8 ± 2.6
4	68.4 ± 2.5
5	66.1 ± 5.3
7	61.7 ± 0.9

See ECBC-TN-019 for more explanation.



APPENDIX 29

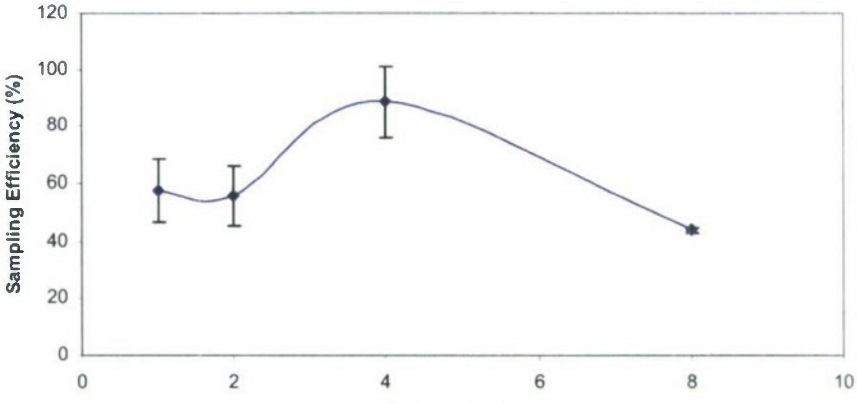
One Stage Andersen Impactor (ECBC-TN-019)

Thermo Fisher Scientific Inc., Waltham, MA

The N6 single stage Andersen viable Impactor uses impaction collection on an agar plate to quantify total viable Colony Forming Units (CFUs). This sampler is comprised of an inlet tube with an approximate 1 in. circular opening, and a single stage with 400 jets for air to pass through and then impact onto the collection surface (Petri dish with media). The single stage Andersen Impactor corresponds to Stage No. 6 of the six-stage Andersen Impactor. The airflow rate is critical for optimal performance of the Andersen Impactor. A separate air pump is necessary for use of the Andersen Impactor. The test was started in March 2002.

Characteristics	Single Stage
Designed airflow rate (L/min)	28.3
Measured airflow rate, at inlet (L/min)	28.3
Power (W) Voltage (V) Current (A)	depends on pump
Physical parameters Weight (lb), w/o pump Height (in.) Diameter (in.)	 1.25 2.9 4.13
Particle Size (µm)	Collection Efficiency (%)
1	57.5 ± 11.2
2	55.8 ± 10.5
4	88.5 ± 12.3
8	43.9 ± 1.0

See ECBC-TN-019 for more explanation.



Particle Size (µm)